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AN EXPERIMENT IN BEEF PRODUCTION IN WESTERN CANADA

A. M. SHAW[1] and J. W. G. MACEWAN[2]

University of Saskatchewan, Saskatoon, Sask.

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INTRODUCTION

This project was planned and started for the purpose of furnishing further information about the merits and characteristics of four breeds of beef cattle and their crosses. It was hoped that the experimental data secured would help to clarify some of the problems which have confronted beef producers on both ranch and farm in Western Canada. Through the life of the project it was considered essential that those connected with the work should attack the problems without prejudice or favour in regard to any breed or cross, and that all data and observations should be recorded systematically.

The tract of range land of some 2,500 acres set aside for the experimental herd was part of the ranch land leased for many years by the Matador Land and Cattle Company, and after being vacated by that Company in 1922 was administered as a community pasture by the Saskatchewan Department of Agriculture. The ranch is situated on the north side of the South Saskatchewan River, north of the town of Swift Current, Saskatchewan.

The main points about which experimental data were sought, follow:

(a) Hardihood and grazing (*i.e.* rustling) qualities of the cow herds when carried under range conditions;
(b) Fertility of the herds;
(c) Weaning weights of the calves of the various breeds and crosses;
(d) Suitability of the calves for feedlot finishing;
(e) Suitability of the finished cattle and their carcasses on the Canadian and British markets;
(f) General information about the problems of exporting cattle and beef to United Kingdom markets.

The project was started in the spring of 1930 with the selection and purchase of the breeding herds, comprising 40 Shorthorns, 40 Herefords, 40 Aberdeen Angus and 40 Galloways. These females were purchased at the age of two years, and while not registered cattle, were well bred and were selected from herds where purebred sires had been used for many genera-

[1] Director of Marketing Service, Dominion Department of Agriculture, Ottawa. Formerly Dean of Agriculture, University of Saskatchewan.
[2] Professor of Animal Husbandry, University of Saskatchewan.

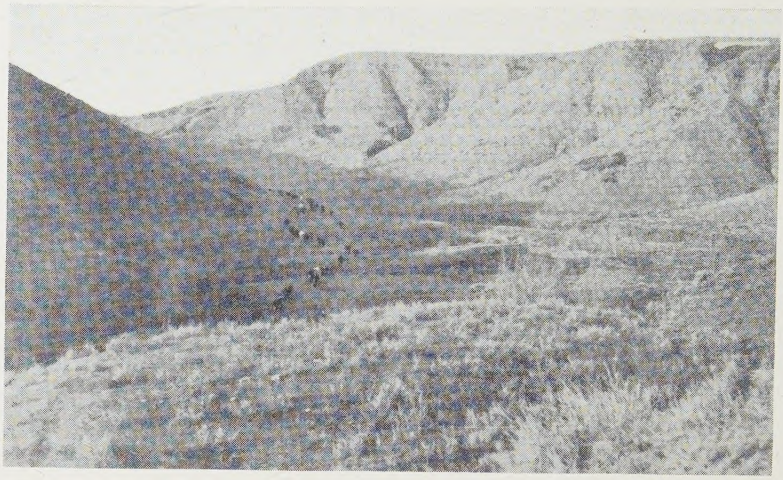

PLATE I. Range scenes on the Matador Ranch, Saskatchewan. *Upper*. Deep coulees such as this provided shelter for the herd during storms. *Center*. Open range. *Lower*. Cattle water hole.

tions. Thus for all practical purposes they were of pure breeding. The importance of securing only cattle which were entirely typical of the respective breeds was fully realized, and many of the best ranch herds of Saskatchewan and Alberta were inspected before the final selections were made. The breeding herds were delivered at the experimental ranch early in June 1930.

The herds were carried under strictly range conditions and were required to graze for most of the year, although some prairie hay was put up for winter emergencies, including times when extreme weather conditions obtained. No grain feed was used at any time. During the winter season the cattle watered at the river, and even in the severest weather they had no shelter except the coulees along the river bank. As with most ranch herds, bulls were placed with the herd on July 1st, and consequently calving started early in April. Calves were weaned each year about the 12th of October and at this time were shipped to the University farm at Saskatoon for winter feeding.

Every effort was put forward to make the experimental conditions as uniform as possible from year to year. This, however, was possible to only a limited degree as weather conditions, the variable quality of feed, and market peculiarities are among the factors about which the experimentalist can do little. As one example of such factors, the weaning weights of calves from year to year are influenced by the abundance, or scarcity, of grass during any particular year. The experimental data, therefore, are scarcely comparable one year with another and the only exact comparisons are those made between the groups during a single year.

The Bulls

Aberdeen Angus bulls were used in the first year (1930), Herefords in the second year (1931), Shorthorns in the third year (1932), and Galloways in the fourth year (1933).

With the exception of the Galloway bulls which were imported from Scotland, all bulls used were bred and raised in Saskatchewan and an endeavour was made to select rugged utility animals rather than highly fitted individuals. White Shorthorn bulls were used in the hope of securing a high percentage of blue and roan calves. For the number of cows on the range, it was considered that 5 bulls would be a sufficient complement each year. The cows of the four breeds ran together and as bulls of one breed only were introduced each year, the resulting calf crop during each year of the project included one group of purebred calves and three groups of cross-bred calves.

The bulls were withdrawn from the range at the conclusion of the breeding season and returned to the University of Saskatchewan farm at Saskatoon. It was obvious that the Galloway bulls survived the breeding season with smaller loss of condition than those of any other breed; they were followed in this respect by the Herefords, Aberdeen Angus and Shorthorns. This observation is consistent with an opinion which ranchers have held, that the Hereford is a better ranch bull than the Shorthorn. While Galloway bulls have not been used extensively in Canada during recent years, hardiness and vigour are characteristics to which they have undisputed claim.

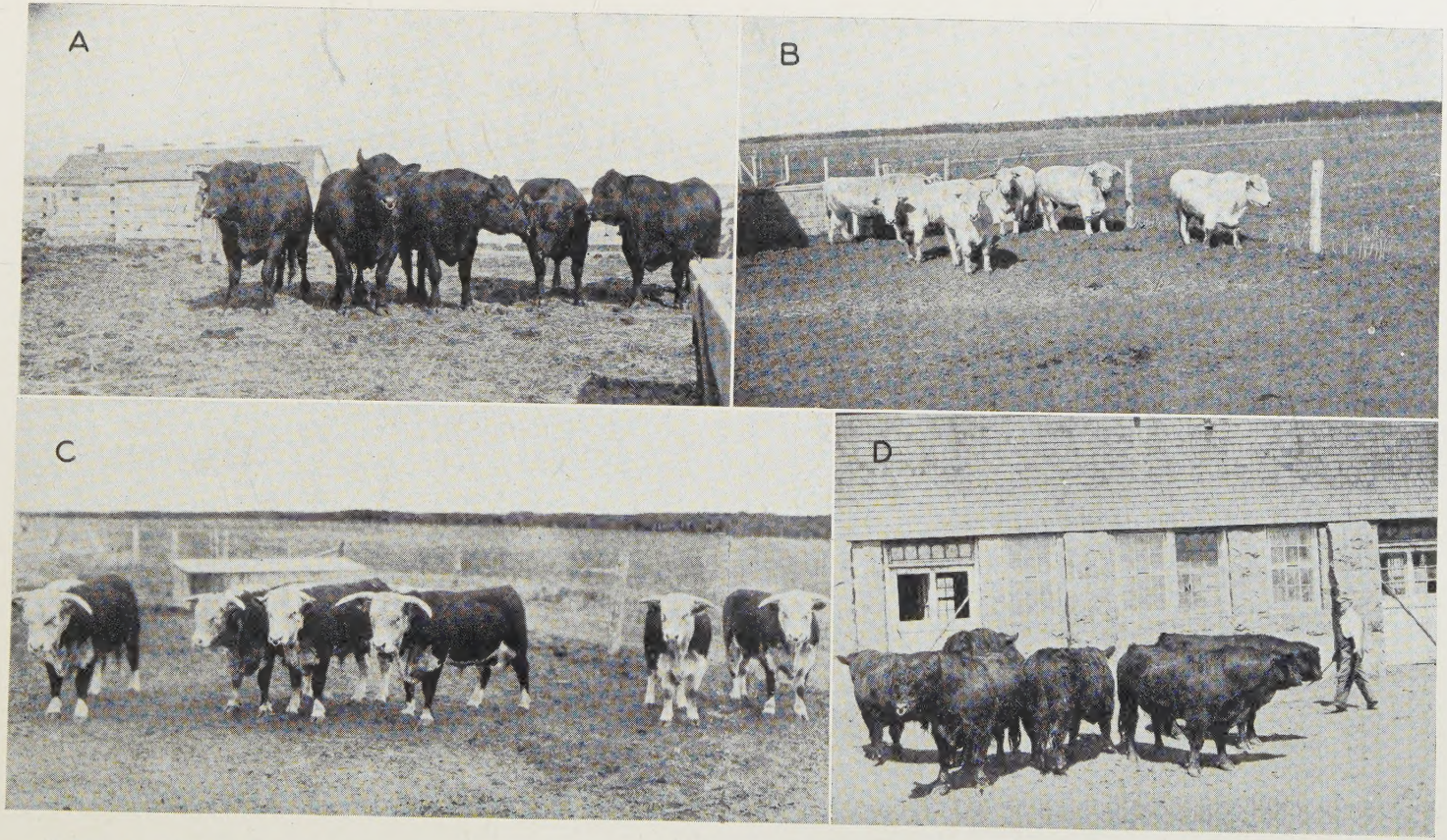

PLATE II. Purebred sires used in experiment. A. Aberdeen Angus bulls. B. Shorthorn. White bulls were selected in order to check inheritance of blue gray colour in crossbreds. C. Hereford bulls. D. Galloway bulls.

Grazing Qualities of the Cow Herds

Mr. George Valentine, Superintendent of the Matador Ranch, who was in close touch with the project, reported on May 13, 1937, concerning the hardihood and grazing qualities of the cattle throughout the life of the project. Mr. Valentine stated emphatically that the Shorthorns were the least hardy and when the "hospital band"[3] was assembled each winter for special feeding, the Shorthorn cows were always in the majority. On one occasion there were 34 cows requiring special attention during the winter and 25 of these were Shorthorns, the remaining 9 being comprised equally of the other three breeds. The Galloways would graze in the open under weather conditions which would drive the other herds to shelter, "but so far as feeding was concerned, the black breeds and the Herefords were about alike." In the spring of 1937, at the age of 9 years the Shorthorns were the poorest, the Galloways and Herefords were about even, and the Aberdeen Angus were the best, according to Mr. Valentine.

Reporting on bad udders, the Shorthorns suffered most from this ailment and two were marketed in 1935 on account of acute udder trouble. The Galloways were second in this respect, the Herefords third, while the Aberdeen Angus were practically free from the complaint. On May 15, 1937, there were 33 Galloways, 35 Aberdeen Angus, 34 Shorthorns, and 33 Herefords in the original experimental herd.

Handling the Calves

The calves were fed and handled from year to year by methods as nearly as possible uniform. On delivery to the University farm the calves were sorted according to breeding, were weighed and placed in the feed lots and the entire crop, both steers and heifers, were finished for market. The feed lots consisted of yards 90′ long × 60′ wide, each equipped with an open shelter on the north side, feed racks in the open and a watering trough at the south side. Hand feeding was practised throughout and was done twice daily. For a few days after being placed in the feed lots the calves were fed on prairie hay and then grain (whole oats) was included in the ration at the rate of one pound per head per day. After a week, the grain ration was increased and was changed from whole oats to a mixture of coarsely ground oats and barley. As a general principle, the proportion of grain was increased by 1 pound per head every 2 weeks until the calves were on full feed; 10 pounds of grain a day was considered "full feed." An allowance of linseed oil cake was added to the grain ration about 10 weeks before the calves were finished, the quantity ranging from $\frac{1}{4}$ of a pound to $\frac{3}{4}$ of a pound. The roughage, which consisted for the most part of prairie hay and oat sheaves, was cut with an ordinary cutting box. Tank heaters were used during the cold weather so that open water was constantly available to the cattle. The calves were weighed at intervals of 28 days.

Number of Calves

The total number of calves produced by each group of cows during the four consecutive years, 1931 to 1934, inclusive was:

Galloway cows,	110 calves.	Hereford cows,	113 calves.
Shorthorn cows,	113 calves.	Aberdeen Angus cows,	113 calves.

A report of each year's crop follows.

[3] Animals requiring special attention.

PLATE III. Cows used in the experiment. A. Aberdeen Angus. B. Shorthorn. C. Hereford. D. Galloway.

THE FIRST CALF CROP—1931

Sired by Aberdeen Angus Bulls

The first calf crop sired by Aberdeen Angus bulls was dropped in the spring of 1931, and 129 calves, representing 1 group of purebred and 3 groups of cross-bred calves were delivered at the University feed lots on October 12 at an average weight of 353 pounds (Table 1, Appendix I). At weaning time the Angus × Shorthorns[4] averaged 1 pound more in weight at 363 pounds than the purebred Angus calves. The Angus-Herefords weighed 354 pounds and the Galloway crosses were the lightest at 336 pounds.

All calves were polled. The Aberdeen Angus × Hereford calves had black bodies and brockle faces, and the Aberdeen Angus × Shorthorn calves were mostly black with a couple of blacks with white bellies and three blue roans. The calves from the Shorthorn, Hereford and Aberdeen Angus cows were quite uniform, while the group from the Galloway cows was uneven.

All the groups took readily to feed, but the Angus × Galloways proved the poorest feeders after the first month. Observations made before the cattle were marketed (June) was that while there were some excellent individuals in the Angus × Galloway lot, they were on the whole the least attractive, not shedding their hair as readily as the others. The Angus × Herefords, at that late date, were pronounced the smoothest, while the Angus × Shorthorns and the straight Angus were the biggest. There was no apparent difference in finish in the last 3 named groups.

A shipment of 112 head, made up of an equal number from each lot, were exported to Birkenhead in June 1932. They sold readily, the respective groups bringing the following average "in sink" prices:

Aberdeen Angus × Galloway	— 9d. per lb.
Aberdeen Angus × Shorthorn	— 9⅜d. per lb.
Aberdeen Angus × Hereford	— 9⅜d. per lb.
Aberdeen Angus × Aberdeen Angus	— 9⅜d. per lb.

A number of the leading cattle and beef authorities passed on the various groups and the consensus of opinion was that the Angus × Shorthorns would place first, Angus × Angus and Angus × Herefords were equal, and the Angus × Galloways were last. Because of the lack of facilities for weighing live cattle at Birkenhead, the exact dressing percentage for each group was not obtained. Most of the carcasses were purchased for the Smithfield market at London. The Angus × Galloway carcasses were the least uniform and least attractive although they were scored higher than when on foot. They carried the lightest kidneys and the least finish, although for economical cutting and the Manchester Market they were almost on a par with the fatter sides. The average weight of the carcasses from the entire Angus × Galloway lot was 386 pounds.

[4]The first named indicates the sire throughout this paper.

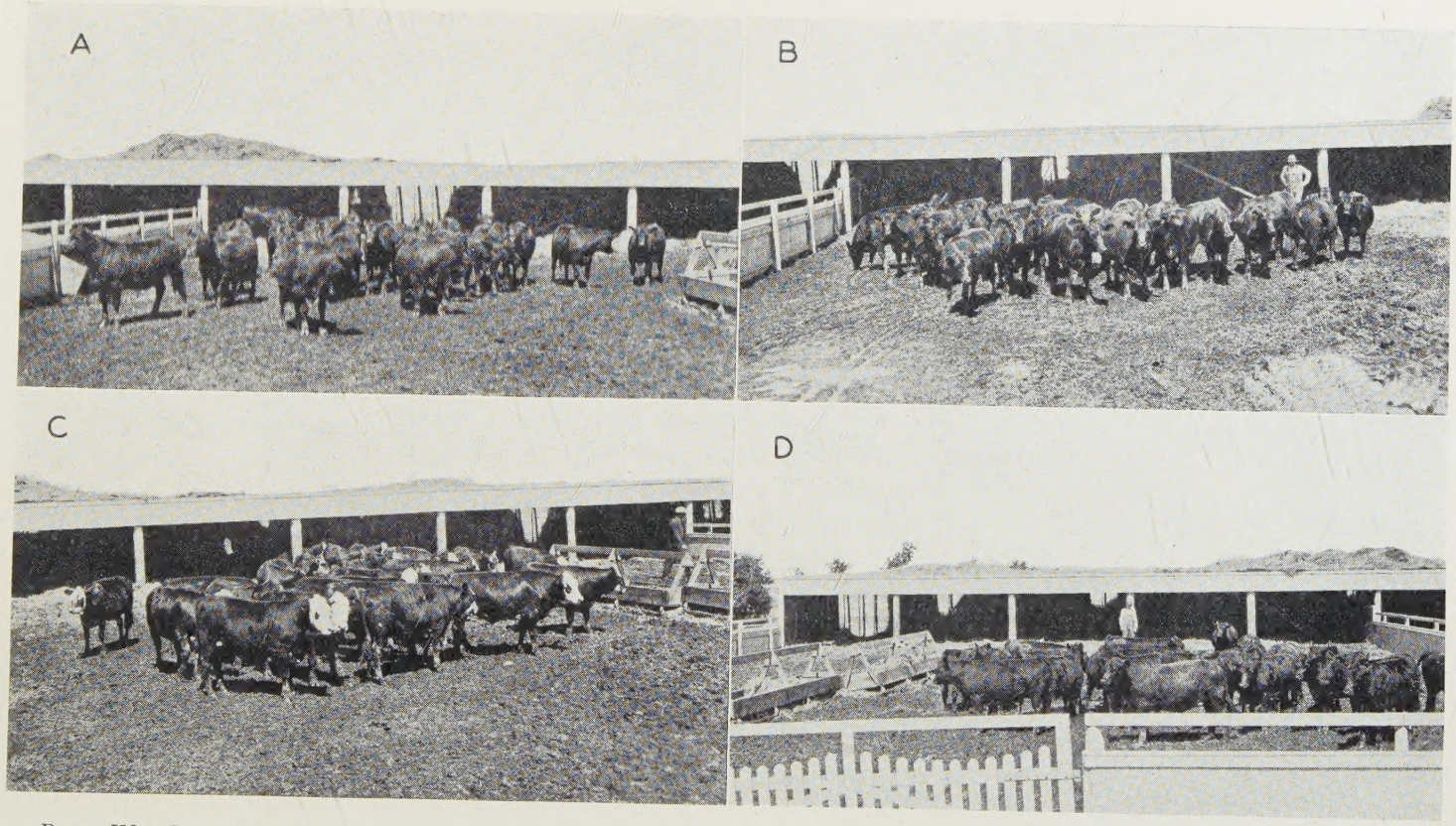

PLATE IV. Calves sired by Aberdeen Angus bulls in feed lot in 1932. A. Aberdeen Angus × Aberdeen Angus. B. Aberdeen Angus × Shorthorn. C. Aberdeen Angus × Hereford. D. Aberdeen Angus × Galloway.

The Angus × Shorthorn carcasses were considered the thickest and fattest but possibly a bit uneven in distribution of fat. They had the heaviest kidney knobs. The average weight of carcasses was 431 pounds, giving the group a weight advantage.

The Angus × Hereford carcasses were not covered over thighs and shoulders as well as those from the Angus × Shorthorn and Angus × Angus. They were criticised for light thighs, but there was an absence of waste, and carcasses averaged 404 pounds cold weight.

The Angus × Angus carcasses scored relatively higher than the live cattle, there being a minimum of waste with a uniform covering of fat. They possessed a superior covering of fat on thighs, shoulders and inner ribs. The thighs showed the best development and the carcasses were pronounced "very useful." The average carcass weight was 413 pounds.

The carcass grades for each lot are shown in Table 2, Appendix I. The best carcass grades were obtained from the Angus × Shorthorn and the Angus × Angus lots. The relative positions of both Angus × Angus and Angus × Galloway were improved when the carcasses were inspected. The carcasses on the whole were pronounced "near ideal" for size, conformation and fatness, some judges advancing the opinion that for the London market a little more weight would be an advantage. Mr. George Roddick of the firm of George Roddick and Sons, Birkenhead, referring to these groups wrote, "The shipment as a whole was the best selling lot to reach this market." Mr. Roddick sent several small shipments to Smithfield market where carcasses were pronounced, "The equal of the choicest Scotch beef." A representative of Gee and Webb Ltd., Central Markets, London, wrote:

"This is the best effort we have yet seen on the part of feeders to meet the changed and modern requirements of the English public inasmuch as these cattle, being small, tender in the flesh and carrying a large amount of meat in proportion to the bone, it is very practical for the retailer to cut small joints and to meet the requirements of the consumer with a minimum amount of waste particularly as regards bone.

"A further feature which presents itself to us regarding the carcasses of beef which we have so far handled has been their striking and attractive appearance—the cattle in no way appear to have suffered from the sea voyage, were perfectly free from bruises and had not the appearance of having gone back in condition.

"We would sum up our criticism of this baby beef by saying that, in our opinion as one of the largest handlers of Scotch beef in Smithfield, this beef has found more favour with our customers than any yet in our experience and, if the production can be organized to keep up a consistent supply, a reputation could speedily be built up for it in Smithfield that would permit of its commanding a price parallel with the choicest of our home products."

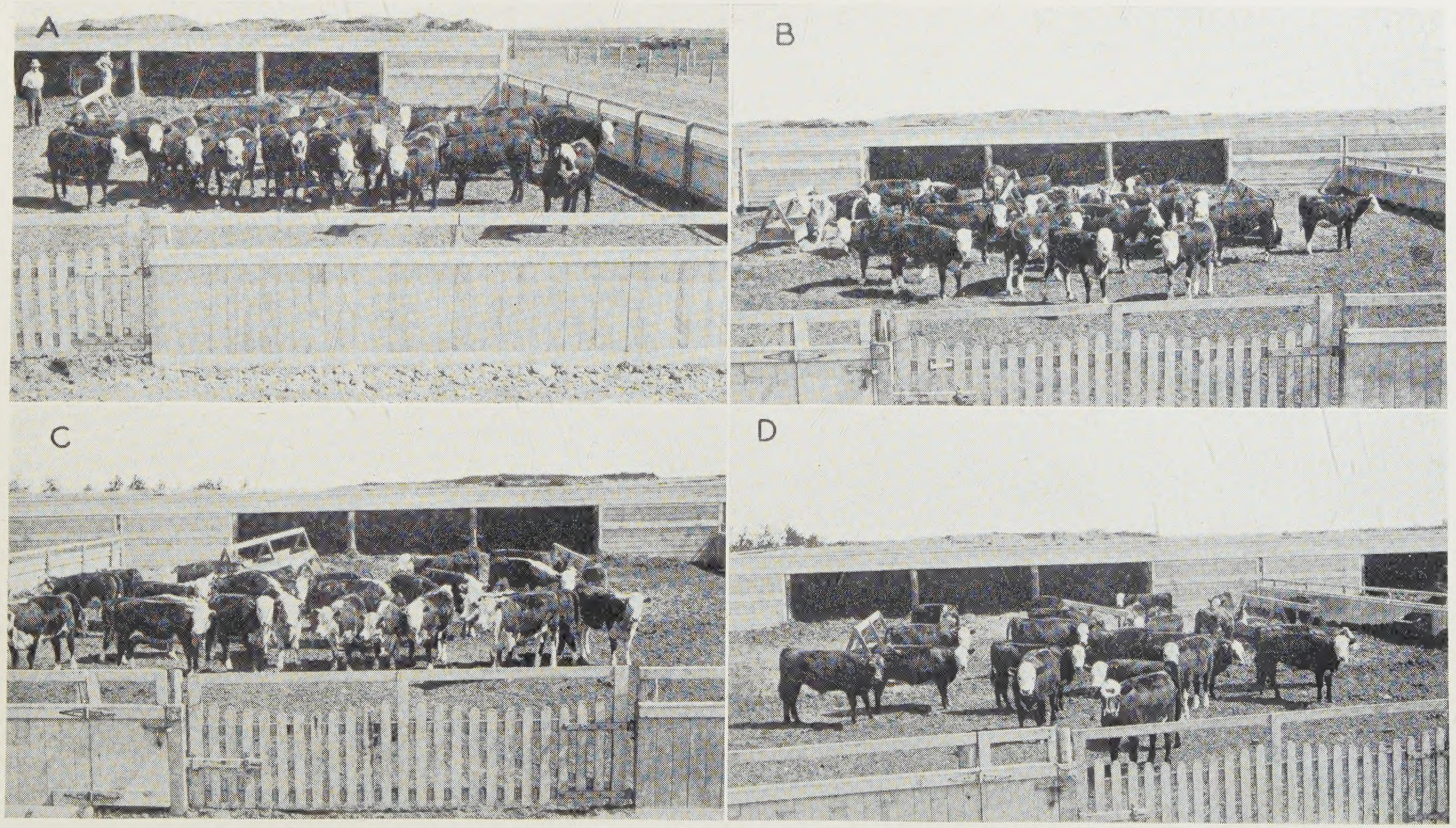

PLATE V. Calves sired by Hereford bulls in feed lot in 1933. A. Hereford × Aberdeen Angus. B. Hereford × Shorthorn. C. Hereford × [illegible] Hereford. D. Hereford × Galloway.

THE SECOND CALF CROP—1932

Sired by Hereford Bulls

The second crop, sired by Hereford bulls was dropped in the spring of 1932, and 112 calves representing 1 group of purebred and 3 groups of crossbred calves were delivered at the University feed lots on October 10 at an average weight of 367 pounds (Table 1, Appendix I). At weaning time the Hereford × Angus crosses averaged 2 pounds more in weight at 378 pounds than the Hereford × Shorthorns. The Hereford × Herefords weighed 362 pounds, and the Hereford × Galloway crosses 352 pounds.

The Hereford × Hereford calves were well marked; the Hereford × Shorthorn calves were reds and roans with white heads, and the Hereford × Angus and Hereford × Galloway calves were black with "broken white" faces and polled. The Hereford × Angus calves and the Angus × Hereford calves of the previous year were marked alike.

It was evident that the Hereford × Hereford calves were the first to finish, followed by the Hereford × Angus. The Hereford × Shorthorn calves were perhaps the rangiest and had the biggest frames, and finished relatively slowly. The Hereford × Angus group was the popular favorite throughout the feeding period, with those who visited the feeding lots. These calves started with a slight increase in average weight and maintained that lead throughout. The Hereford × Galloway group was superior to the Angus × Galloway group of the previous year; the first named had many excellent individuals but was criticised for lack of uniformity and slowness in finishing. Comparing the entire crop of calves with the 1931 crop (the 1931 crop being sired by Angus bulls) it was observed that the 1932 calves had better tops, but poorer hind quarters and lighter thighs. Those from the Hereford sires showed more evidence of patchiness around the tail-head, and the hides were thicker and coarser.

A shipment of 100 head of representative finished calves, 25 from each pen, were exported to Birkenhead in June (Table 2, Appendix I) the balance being marketed in Winnipeg. The general opinion of the Birkenhead cattlemen and dealers was that the Hereford × Angus group was superior for size, uniformity, quality and finish. The Hereford × Hereford lot which were placed next were criticised for being small, but had greater smoothness and uniformity than the Hereford × Shorthorn. The Hereford × Galloway lot had some good and some plain and underfinished individuals and the heifers were pronounced much better than the steers.

On the rail, there was little evidence of definite superiority of one group over any other. The only consistent comment was that the Hereford × Angus carcasses excelled in weight and smoothness and had the most kidney fat. The Hereford × Galloway carcasses showed the poorest finish. Dealers pronounced the Hereford × Angus, Hereford × Shorthorn, and Hereford × Hereford carcasses of approximately equal value, and the Hereford × Galloway carcasses worth about a half penny a pound less. The average carcass weight for the entire shipment was about 426 pounds, and although the quality and fatness were both most acceptable, carcasses weighing slightly heavier would have been more suitable for the London trade.

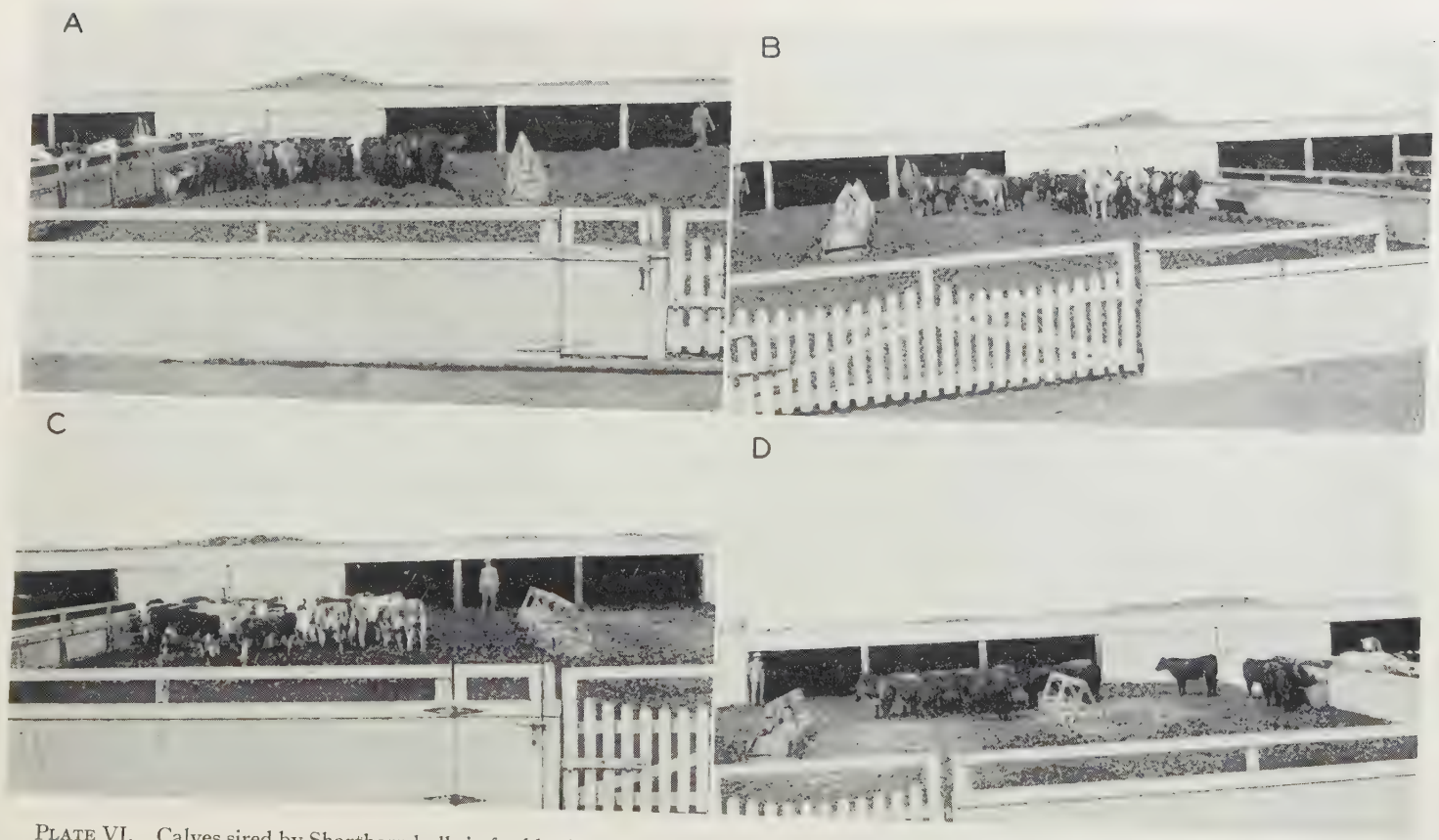

PLATE VI. Calves sired by Shorthorn bulls in feed lot in 1934. A. Shorthorn × Aberdeen Angus. B. Shorthorn × Shorthorn. C. Shorthorn × Hereford. D. Shorthorn × Galloway.

THE THIRD CALF CROP—1933

Sired by Shorthorn Bulls

The third and smallest crop, sired by Shorthorn bulls was dropped in the spring of 1933, and 77 calves representing 1 group of purebred and 3 groups of cross-bred calves were delivered at the University feed-lots in October at an average weight of 362 pounds (Table 1, Appendix I). At weaning time the Shorthorn × Aberdeen Angus averaged 376 pounds and weighed 4 pounds more than the Shorthorn × Galloway calves. The Shorthorn × Hereford crosses weighed 358 pounds and the Shorthorn × Shorthorn animals 347 pounds.

The Shorthorn × Galloway and Shorthorn × Angus were without exception polled. They were all blacks and blues.

There were about the same number of blues in each of the two groups. The Shorthorn × Hereford were mostly red roans with a few reds and all had clear white heads. They had, perhaps, the most attractive appearance. The Shorthorn × Shorthorn, although from white bulls, were predominately roans and reds, there being but three whites in the lot.

The pen of Shorthorn × Shorthorn appeared to suffer most from the cold during the winter months. The Shorthorn × Angus and Shorthorn × Hereford groups were the first to finish and the former group was the favorite with the majority of cattlemen who inspected the groups, when judged from the standpoint of size and quality.

In order to obtain information about the practicability of slaughtering export cattle in Canada and exporting the carcasses as refrigerated beef, the crop of calves was divided and slaughter data and carcass records obtained from Saskatoon, Montreal and Birkenhead. The division of the cattle was not according to breed; one-third (26 head) of the entire crop was exported on foot and slaughtered at Birkenhead; one-third (26 head) was slaughtered at Montreal, where the carcasses were prepared and exported to London, and the remaining one-third (25 head) was slaughtered at Saskatoon, their carcasses prepared and exported via Montreal (Table 1, Appendix I). The project was so planned that carcasses from each of the three lots were offered for sale on the Smithfield Market, London, at the same time. The report of this phase of the project dealing with the dressed beef has already been published;[5] (see Appendix II for Comment and Conclusions).

Although the original breed groups were broken to facilitate the dressed beef experiment, the identity of the carcasses was retained and comment and carcass records obtained for each group. The Shorthorn × Hereford calves were the first to finish but did not attain as much weight as the Shorthorn × Galloway or Shorthorn × Angus, and were the lowest in average daily gains. The Shorthorn × Shorthorn lot had big frames but were slow to finish and were considered the least attractive. The Shorthorn × Angus group was favoured on foot and had the highest percentage of top grade carcasses. The carcasses of this group were excelled in fatness by the

[5] Shaw, A. M. Report on Experimental Shipment of Chilled Beef to Britain, report published, 1934.

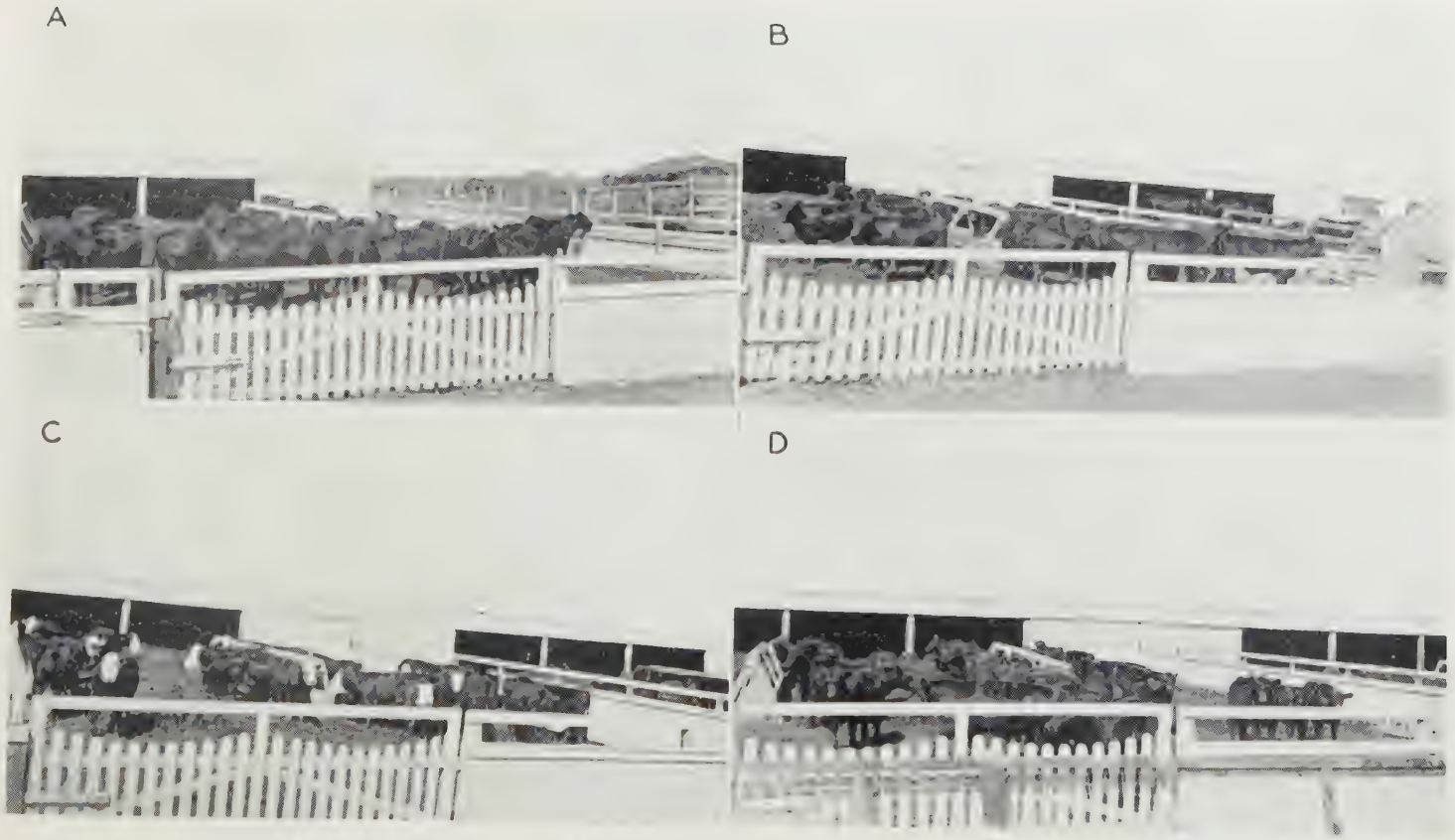

PLATE VII. Calves sired by Galloway bulls in feed lot in 1935. A. Galloway × Aberdeen Angus. B. Galloway × Shorthorn. C. Galloway × Hereford. D. Galloway × Galloway.

Shorthorn × Hereford carcasses, but the former showed the best degree of firmness and more even distribution of the fat including a better covering on the inside of the ribs. This Shorthorn × Angus group combined size with quality to probably the best degree. The Shorthorn × Hereford carcasses were pronounced the fattest, and a few of the carcasses, principally from heifers, were considered too fat for the average trade. The Shorthorn × Galloway carcasses were a little more variable, some were excellent for finish, and others distinctly lacking in that respect. The Shorthorn × Shorthorn calves were the poorest of the four groups for finish, a few of them being well covered but collectively they lacked uniformity. As a group they were at somewhat of a disadvantage because of the number of late calves in the lot.

THE FOURTH CALF CROP—1934

Sired by Galloway Bulls

The fourth crop, sired by Galloway bulls was dropped in the spring of 1934, and 130 calves representing 1 group of purebred and 3 groups of cross-bred calves were delivered at the University feed-lots in October (Table 1, Appendix I). At weaning time the Galloway × Shorthorn calves averaged 371 pounds in weight, the Galloway × Hereford and the Galloway × Aberdeen crosses weighed the same at 359 pounds and the Galloway × Galloway were the lightest at 343 pounds.

The Galloway × Hereford calves were all marked as the Hereford × Galloway calves of an earlier year, black with "broken white" faces. There were two blue roans in the Galloway × Shorthorn pen and all others were black. All calves were polled.

It was noticeable in feeding that all groups consumed somewhat less roughage than those of former years, while the group of Galloway × Galloway showed a particularly small appetite for roughage. There has been increasing evidence that the Galloway in the pure state is a comparatively slow feeder. Before marketing, the Galloway × Shorthorn calves appeared the best, although the Galloway × Hereford calves had been first to finish.

Owing to circumstances over which there was no control, it was considered unwise to export these groups to the British market. They were, therefore, shipped to Winnipeg and slaughtered under the same degree of supervision as was employed in former years (Table 2, Appendix I). Carcass grades were adapted as nearly as possible to the Old Country standards. Dressing yields were obtained for the Winnipeg slaughtered cattle and the cold dressed yield for the four lots was as follows:

Galloway	× Galloway	58.6%
"	× Shorthorn	61.0%
"	× Hereford	60.6%
"	× Aberdeen Angus	60.0%

The carcasses from the Galloway × Shorthorn lot were perhaps the fattest; Mr. Trantor of the firm of Canada Packers Ltd. stated regarding these; "The chief criticism is that the heifers are inclined to be over-finished

and a little patchy around the tail." They were, however, thick, meaty carcasses that dressed out well. The Galloway × Angus carcasses carried the most uniform covering of fat, especially over the thighs and shoulders, and on the inside of the rib. The same carcasses, however, were scarcely as thick over the back, and several were under-finished. The heifer carcasses in this lot were clearly smoother than the heifer carcasses from Galloway × Hereford and Galloway × Shorthorn. The Galloway × Hereford carcasses were relatively uniform for weight and quality, and carried a desirable degree of finish. In analyzing the utility of the various groups of carcasses, Mr. Trantor observed that, "there is little to choose between the Galloway × Hereford, Galloway × Angus and Galloway × Shorthorn and this is particularly true with the Galloway × Hereford and Galloway × Angus." The Galloway × Galloway carcasses were relatively uneven, and while there were some excellent carcasses there were some that were definitely lean and lacking in thickness, as the tabulated carcass grades show. Many of the carcasses were deficient behind the shoulders. Based on carcass values, Canada Packers Ltd. appraised the Galloway × Shorthorn, Galloway × Angus and Galloway × Hereford groups at precisely the same figure and the Galloway × Galloway group at 0.75c. per cwt. lower on a live weight basis.

DISCUSSION

In view of the impossibility of maintaining experimental conditions at the same degree of uniformity from year to year, the differences shown in feed consumed per unit increase in weight, for the different crops of calves, may be of no more than general interest. The grain and roughage consumed by the calves from each breed of sires is shown in the following:

	Consumed per 100 lbs. gain	
	Grain	Roughage
	lbs.	lbs.
1931-32 Calves sired by Aberdeen Angus bulls	338.5	748.5
1932-33 " " " Hereford bulls	451.0	678.0
1933-34 " " " Shorthorn bulls	418.5	747.6
1934-35 " " " Galloway bulls	429.0	562.0

Without stretching the imagination it would be impossible to conclude from this project that any single breed or cross is greatly superior or greatly inferior to all others. Perhaps one of the most significant things has been the similarity between the groups in point of utility and suitability. Certain differences already shown, however, may have significance. From the data presented, the cross-breds on the whole appear to have had a slight advantage over the purebreds in rate of gain, finish and suitability of carcasses. Of the purebred groups, the Galloway made the poorest showing, although in recognizing possible Galloway limitations for fed calf or baby beef production, consideration must be given to other characteristics, particularly that of their greater hardiness which make the breed suitable

as ranch cattle. The Shorthorn, a breed which has quite fairly and rightly earned a place of prominence on the Western farms, was in third position in this baby beef test, while the Herefords made the best showing and the Aberdeen Angus second.

There was no sound evidence that reciprocal crosses were in any way different, either in appearance or as producers of beef. In studying the crosses, therefore, it seems expedient to examine them as reciprocal pairs, considering for example, the Shorthorn × Hereford, and Hereford × Shorthorn, together. Proceeding in this manner and weighing all evidence available, the Angus × Shorthorn, and Shorthorn × Angus crosses seem to warrant highest honors. Judged on percentage of top grade carcasses the paired groups and single breeds appear in the following order:

	Average daily gain when on feed	Percentage of top grade carcasses
	lbs.	%
1. Shorthorn × Aberdeen Angus Aberdeen Angus × Shorthorn	1.82	86.4
2. Hereford × Shorthorn Shorthorn × Hereford	1.73	84.4
3. Hereford × Hereford	1.67	84.0
4. Aberdeen Angus × Aberdeen Angus	1.72	75.7
5. Aberdeen Angus × Hereford Hereford × Aberdeen Angus	1.72	67.8
6. Hereford × Galloway Galloway × Hereford	1.73	66.6
7. Shorthorn × Shorthorn	1.77	65.2
8. Shorthorn × Galloway Galloway × Shorthorn	1.77	61.7
9. Aberdeen Angus × Galloway Galloway × Aberdeen Angus	1.69	45.7
10. Galloway × Galloway	1.61	14.0

SUMMARY

1. The suitability of ranch bred calves for finishing in farm feed-lots was well established.

2. Heifer calves finished approximately 30 days earlier than steer calves. This held true with all groups.

3. The experiment served to show that young cattle of good breeding can be converted into a finished beef product capable of commanding the best market price in either Canada or Great Britain.

4. The shipping of Canadian fresh beef seems to warrant further investigation. The trial shipments served to show on the one hand, a great possible advantage, and on the other, the many obstacles to be overcome before the trade could be established.

5. The Galloway bulls withstood the hardships of the range much better than the bulls of the other breeds. The Herefords were second, the Aberdeen Angus third, and the Shorthorns fourth.

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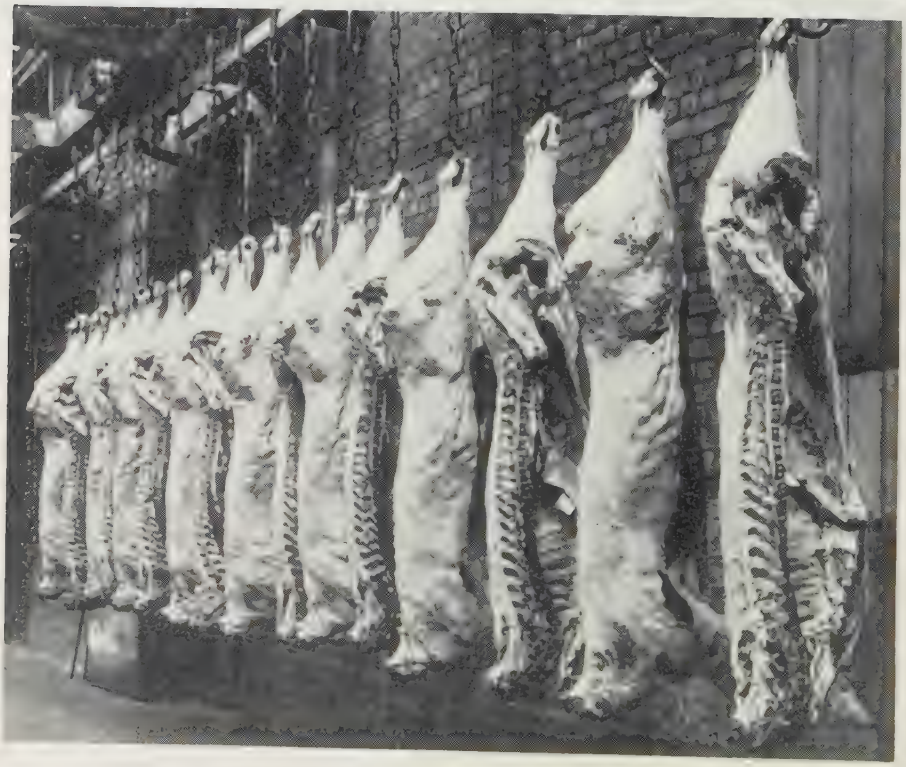

PLATE VIII. Carcasses at Birkenhead Market, England, 1932. A number of these were forwarded to London and sold on the Smithfield Market at prices equalling the best Scotch sides. *Upper.* Aberdeen Angus × Aberdeen Angus. *Lower.* Aberdeen Angus × Galloway.

PLATE IX. Carcasses at Birkenhead Market, England, 1932. A number of these were forwarded to London and sold on the Smithfield Market at prices equalling the best Scotch sides. *Upper.* Aberdeen Angus × Hereford. *Lower.* Aberdeen Angus × Shorthorn.

6. There was no difference in the fertility of the cow herds. The Shorthorn, Hereford and Aberdeen Angus cow herds each produced the same number of calves in 4 years.

7. The cow herds in their tenth year were almost equal in numbers, indicating negligible difference in depreciation due to death loss or sterility.

8. The calves from the Aberdeen Angus cows averaged the heaviest at weaning time, followed by those from the Shorthorns, Herefords and Galloways.

9. No single breed or cross was outstanding in the feed-lot. The Galloway breed made the poorest showing in this respect, and it was clear that the pure Galloways were less suited to baby beef production, requiring longer to finish.

10. The cross-breds had a definite advantage over those of pure breeding in rate of gain and quality of carcass.

11. Reciprocal crosses produced cattle of similar colour markings and from the evidence, equal utility and quality.

12. In studying paired groups of crosses (reciprocal crosses grouped together) the Shorthorn × Aberdeen Angus and the Aberdeen Angus × Shorthorn gave the best results, as measured by the percentage of top grade carcasses. The superiority of the calves of this breeding is consistent with many opinions held in Britain, as much of the best Scotch beef shipped to Smithfield Market is a product of the Aberdeen Angus × Shorthorn cross.

APPENDIX I

TABLE 1.—WEANING WEIGHTS AND GAINS OF CATTLE—BEEF PRODUCTION PROJECT 1931-1934

Cattle	Year of birth	Number received at feed-lot	Average weaning weight	Losses during feeding	Average weight at close of feeding period	Average daily gain for period
			lbs.	No.	lbs.	lbs.
Aberdeen Angus × Galloway	1931	34	336	1	739	1.60
" " × Shorthorn	1931	25	363	0	814	1.79
" " × Hereford	1931	36	354	0	776	1.67
" " × Aberdeen Angus	1931	34	362	1	796	1.72
Hereford × Galloway	1932	26	352	1	769	1.67
" × Shorthorn	1932	29	376	0	800	1.70
" × Hereford	1932	30	362	0	778	1.67
" × Aberdeen Angus	1932	27	378	3	819.6	1.77
Shorthorn × Galloway	1933	17	372	0	790	1.78
" × Shorthorn	1933	23	347	0	763	1.77
" × Hereford	1933	18	358	0	772	1.76
" × Aberdeen Angus	1933	19	376	0	812	1.85
Galloway × Galloway	1934	33	343	0	735	1.61
" × Shorthorn	1934	36	371	0	800	1.76
" × Hereford	1934	29	359	0	796	1.80
" × Aberdeen Angus	1934	33	359	0	794	1.79

TABLE 2.—CARCASS GRADES—BEEF PRODUCTION PROJECT 1931-1934

Cattle	Year of birth	Number for which carcass grades reported	Carcass grades*			Percentage of top grade carcasses
			1	2	3	
			No.	No.	No.	%
Aberdeen Angus × Galloway	1931	33	14	12	7	42
" " × Shorthorn	1931	25	20	5	—	80
" " × Hereford	1931	36	21	10	5	58
" × Aberdeen Angus	1931	33	25	7	1	75
Hereford × Galloway	1932	25	20	5	—	80
" × Shorthorn	1932	27	22	3	2	81
" × Hereford	1932	25	21	4	—	84
" × Aberdeen Angus	1932	23	19	4	—	83
Shorthorn × Galloway	1933	17	14	2	1	82
" × Shorthorn	1933	23	15	6	2	65
" × Hereford	1933	18	16	2	—	89
" × Aberdeen Angus	1933	19	18	1	—	95
Galloway × Galloway	1934	22	3	11	8	14
" × Shorthorn	1934	30	15	15	—	50
" × Hereford	1934	26	14	11	1	54
" × Aberdeen Angus	1934	26	13	13	—	50

* The carcass grades designated 1, 2, 3, are based on British standards and may be considered approximately equivalent to "Choice," "Good," and "Medium."

APPENDIX II

From Report on Experimental Shipment of Chilled Beef to Great Britain. A. M. Shaw

The results obtained from the experimental shipment of chilled beef to Britain seemed to justify the following comment:

1. The most profitable shipment was No. 1, where the cattle were shipped alive to Birkenhead, England, and sold "in sink" at that point.
2. There appeared to be little difference on arrival in the appearance or condition of the carcasses prepared in Saskatoon as compared with those prepared in Montreal.
3. Although there was little difference in the returns from the Saskatoon and Montreal lots ($1.74 per head) it is probable that a shipment killed in Montreal is exposed to less chance of temperature variation than one killed in Saskatoon and shipped to Montreal in refrigerator cars. Further, the Saskatoon beef arriving in England is 4 to 5 days older than that killed in Montreal. The latter has a better chance of arriving in good condition.
4. The temperature in the refrigerator cars is not uniform throughout the car, being lowest at the two ends at the bottom and highest in the centre at the top. Although this is perhaps not so important in the case of certain products, the range of safety in the case of beef is so small that, if the car temperature is such that the sides hung at the ends are at the correct temperature, those in the centre will be exposed to a temperature very much too high.

5. It is not possible to hang large sides (over 7 feet in length) in refrigerator cars owing to lack of height; and, as quartering detracts from the value of the carcass, it would seem that inland killing and shipment, chilled in sides, of 2-year-old or larger animals is impossible. The same is true of the refrigeration chamber on board ship, only a few ships have sufficient head room to handle large carcasses.
6. At present prices, it would seem to be more profitable to ship the edible offal frozen to Great Britain than to sell it in Canada.
7. It is evident that the success of the Canadian chilled beef trade will be controlled by the condition of the chilled beef arriving at Smithfield. The avoidance of "souring" and "bone taint" is essential and therefore the time elapsing between the slaughter of the beef and its appearance on the stall in Smithfield should be as short as possible.
8. Time might be saved in the pre-cooling process by chilling the freshly killed beef more rapidly. In the case of the Montreal and Saskatoon lots, 48 hours of gradual chilling were allowed at chamber temperature of about 34° F.
9. Shipping chilled meat with other commodities in the same chamber is unsatisfactory.
10. The practice of shrouding the carcasses appears to have no commercial value in the British market. British beef is never shrouded.
11. Moulds which frequently give trouble in meats held at high temperatures were entirely absent in this shipment.
12. No trouble was experienced from condensation. The meat, when removed from the refrigeration chamber to the market, did not "drip" or "sweat" in the slightest degree.
13. Close observation of various shipments under different conditions prompts the belief that only where meat is held at a temperature sufficiently low to form ice crystals in the outer layers does the question of condensation become of practical importance.
14. Forwarding chilled beef presents much greater difficulties than those encountered in the handling of a semi-frozen product.
15. Varying temperatures to which the meat was exposed during loading and transferring from cars and abattoirs to the ship together with additional and unavoidable delay at London in all probability was partly responsible for the unsatisfactory condition of the meat on arrival.
16. The meat was in perfect condition when leaving Montreal. On arrival in London, slight deterioration was noticeable. Whether this was due to temperature or time factors or a combination of both is not clear, although there is reason to believe that the rapidity of cooling is directly related to the condition recognized as "bone taint" in chilled meat.
17. The question of proper rate of cooling and correct temperatures at which to carry chilled meat from Canada is still to be worked out.

In conclusion, it might be said that Canadian chilled top quality baby beef is entirely suitable for the British market as far as conformation, type and finish are concerned, and if the meat can be landed in good condition, the likelihood is that the price would closely approach that of the home-grown or home-killed product. This means that it would command a price very much higher than that ordinarily obtained for the products of the Argentine and Australia. In the face of this, however, is the fact that, even though these prices could be obtained for the chilled product, this experiment has demonstrated that the same class of cattle forwarded alive will be likely to net a greater return.

A COMPARATIVE STUDY OF RAPID CHEMICAL TESTS AND NEUBAUER ANALYSES ON SOME TYPICAL SOUTHERN ONTARIO SOILS[1]

G. N. Ruhnke[2], C. P. Rivaz[3], and W. T. Ewen[4],
Ontario Agricultural College, Guelph, Ontario.

INTRODUCTION

The demand for more specific information regarding fertilizer requirements of cultivated soils has led to the extensive use of rapid chemical tests in connection with fertility problems. In Ontario, the rapid soil tests have been employed by horticulturists, agronomists, soil specialists, and extension workers with considerable success, in the development of an organized soils advisory service.

It has been recognized, however, that in order to make the rapid methods more effective for this purpose, some attempt should be made at standardization and calibration for Ontario conditions. Little difficulty has been encountered with the pH and lime requirement estimations. The more urgent problem is that of obtaining reliable tests for available phosphorus and potassium.

It need scarcely be pointed out that, to be useful, any rapid test must reflect fairly accurately the actual plant availability of the soil nutrient in question. A knowledge of this availability may be gained by field experiments, pot culture trials, or by one of the biological laboratory methods. For exact standardization of the chemical tests, results of carefully laid out fertility experiments on a wide range of soil types are necessary, but in view of the expense involved, and of the time which must elapse before conclusions may be drawn, a more convenient and rapid biological basis is desirable. That the Neubauer (3), (4), (5) rye-seedling method of soil analysis is well suited for the estimation of the availability of phosphorus and potassium has been demonstrated by the majority of workers who have given it a fair trial. The method has been widely used in Germany where it originated, but a review of the references to it in the German literature is not possible in this paper. Of the American workers, Thornton (8, 9) has used the procedure most extensively. In a comparison with chemical methods, using soils from fertility experiment fields, he found that the method accurately portrayed known deficiency symptoms, and was in close agreement with results from field tests and pot experiments, when proper consideration was given to other possible limiting factors. Pettinger and Thornton (6) found a high correlation between Neubauer analyses and stalk test values and sap analysis results. Dahlberg and Brown (2) report the use of the Neubauer method in determining the available phosphorus supply of a large number of sugar beet soils in Colorado. They consider the method accurate and reliable, having checked

[1] Contribution from the Soils Laboratory, Department of Chemistry, Ontario Agricultural College. Presented before the Soils Group of the Canadian Society of Technical Agriculturists at Ottawa, Ont., June 27–30, 1938.
[2] Professor and Head of the Department.
[3] Research Assistant.
[4] Research Assistant.

their findings by field trials. Volk and Truog (11), in applying their method of potassium analysis to a group of soils on which Neubauer data were available, found a definite relationship between exchangeable potassium and that extracted by the rye-seedlings. Wheeting (12) compared Neubauer analyses for potassium with several chemical methods of extraction. He concluded that the method detected quite accurately the potassium deficiencies of soils. He also obtained concordant results when Neubauer estimations for potassium, and alfalfa yields in greenhouse pot cultures were compared. Snider (7) found that the results obtained by the rye-seedling and Truog methods for determining the availability of phosphorus compared favourably with wheat yields on phosphate treated plots. Both methods were suitable for determining the range of fertility in which added phosphorus was necessary.

In recent studies of Ontario soils by the Neubauer method, good correlation has been found between crop response to fertility treatments and the levels of available phosphorus and potassium indicated by the rye-seedlings. These investigations were carried out on representative soils, covering a considerable range of field conditions and fertility levels. As a result of these studies, and the satisfactory experience referred to above, it was decided to obtain Neubauer data on a much larger number of samples as a basis for calibration of rapid chemical tests for phosphorus and potassium.

MATERIALS AND METHODS

Several methods of testing have been studied at this institution, but because of its simplicity, and the fact that it combines plant tissue and soil tests, the Thornton (10) system has been generally employed for extension use. For this reason, special attention has been given to the Thornton tests, and while it has been found that the method for potassium is fairly satisfactory, the phosphorus test is unreliable for certain soil types.

For the phosphorus test, the extracting solution is approximately 0.75 N HCl, which is about the same strength as that originally used by Bray (1), in Illinois, in one of the first rapid soil tests developed. Bray (1) and Thornton *et al.* (10) have called attention to the limitations of the test when applied to alkaline and calcareous soils. It has been the experience in this laboratory that this strength of extracting solution gives too high readings for phosphorus, with soils definitely known to respond to phosphate fertilizers.

In an attempt to overcome this difficulty, other concentrations of extracting solution were tried out and the results compared with the regular Thornton test and Neubauer data. Ultimately it was found that a hydrochloric acid solution, of approximately 0.05 N strength, was most satisfactory, when the procedure was modified somewhat from the original. The test developed in this laboratory is referred to as the "Modified Thornton Method", the reagents and procedure for which are as follows:

Reagents

1. Extracting solution—Dilute 4 cc. concentrated HCl (12 N) to 1 litre with distilled water. This gives a 0.05 N HCl solution (approx.).

2. Molybdate reagent—Thornton's concentrated stock solution. Dissolve 20 gms. of ammonium molybdate in 500 cc. of distilled water and add, slowly and with constant stirring, a mixture of 315 cc. concentrated HCl and 185 cc. of distilled water.

3. Reducing agent—Dry powdered stannous chloride or stannous oxalate.

Making the Test

As in the Thornton method, to 10 cc. of the extracting solution in a vial, add ½ teaspoon level full, of air-dry soil. Shake for one minute and filter. To a 5 cc. aliquot, add 1.25 cc. of the molybdate reagent and mix well. Develop the full colour with the minimum amount of stannous chloride or oxalate. Compare with the Thornton phosphorus colour chart in the regular way.

For the modified phosphorus test as outlined above, the ratings on the Thornton phosphorus chart have the following equivalents expressed in pounds of P_2O_5 per acre.

Test Rating	*Pounds per acre P_2O_5*
Very low	6
Very low	13
Low	40
Medium	100
High	130

These values have been determined by matching the tests on the soil extracts with colour standards developed from solutions of known phosphate concentration and calculating the results to an air-dry soil basis.

COMPARISON OF RESULTS OF RAPID TESTS AND NEUBAUER ANALYSES

In the following series of charts, comparisons have been made of (1) the results for phosphorus by the Thornton, Modified Thornton, and Neubauer methods, and (2) the results for potassium by the Thornton and Neubauer methods, on a large number of representative Ontario soils. The tables of data on which the charts are based have been omitted to conserve space, as it was felt that in reporting this investigation the general trend of results was of more significance than the individual values.

The vertical scales on the charts represent pounds per acre of surface soil. For both rapid test and Neubauer methods, results for phosphorus are expressed as P_2O_5, and for potassium as K_2O. The equivalent pounds per acre, corresponding to the various ratings for the Thornton phosphorus and potassium tests, were kindly supplied by Dr. Thornton. For the Modified phosphorus test, the equivalents were determined as previously described.

To provide a basis for a broad classification of the soils into deficient and non-deficient groups, the tentatively adopted limiting values (Thornton) for Neubauer available phosphoric acid (80 pounds P_2O_5 per acre)

and potash 200 pounds (K_2O per acre) have been indicated on the charts. In all cases the results have been arranged in the order of increasing values from Neubauer analysis. Since soil reaction is of considerable interest, especially in the case of the phosphorus tests, the pH value for each sample is given at the bottom of the charts.

In Figure 1, results are presented for the Thornton, Modified Thornton and Neubauer tests for phosphorus, on soils from the corn belt in Southwestern Ontario. These samples were specially selected from fields of known history, in which studies of deficiency symptoms in corn plants were made. The letter "D" at the bottom of the chart indicates a sample from a field in which the crop showed definite symptoms of phosphorus deficiency.

The Neubauer results are closely related to the cropping and manuring history of these fields. In those cases where low Neubauer phosphorus results have been obtained but no deficiency symptoms in the plants are indicated, hill and drilled-in-row applications of complete fertilizers were made for the corn crop. Since all samples were collected from between the rows, the effect of the fertilizers on the soil test was purposely avoided.

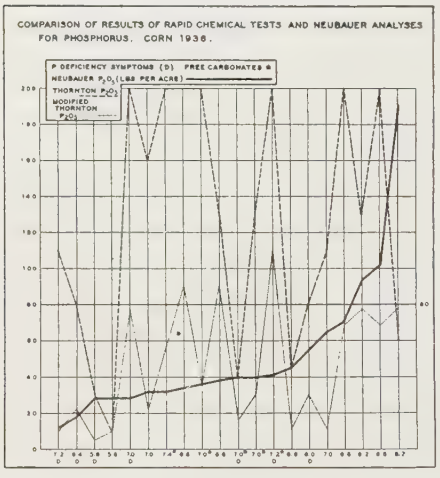

FIGURE 1

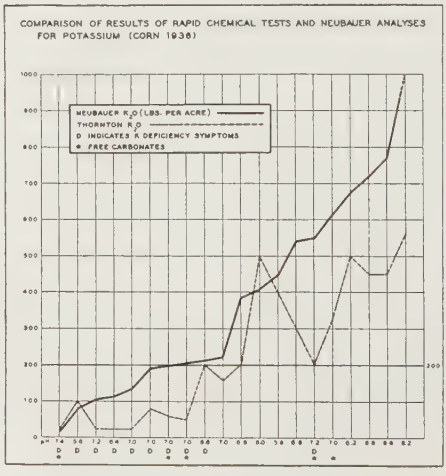

FIGURE 2

The first and last samples in the series represent two extremes of fertility and crop conditions. In the field represented by the first sample, the crop was practically a complete failure and almost all corn plants showed extreme signs of both phosphate and potash deficiencies. No commercial fertilizer had been used on this field. In the field represented by the last sample, the crop showed no signs of deficiency symptoms of any kind and was rated as one of the best in the locality. This field had never received commercial fertilizer but has always been liberally manured for the wheat and corn crops, and clovers always have been included regularly in the rotation.

Although neither of the chemical tests check well with the Neubauer method, the results by the Modified Thornton test show less disagreement

for the majority of the samples. These soils include a considerable range in pH values and a wide range in texture and organic matter content, hence a better agreement between chemical and Neubauer methods may be scarcely expected.

The results for potassium by the Thornton test and the Neubauer method on the corn soils, have been plotted in Figure 2, where the wide range of potassium levels covered is evident. Good correlation exists between potassium deficiency symptoms exhibited in the crop and the rye-seedling results. One exception may be noted, however, in the case of soil No. 15. Here the Neubauer results are quite high, while a very slight

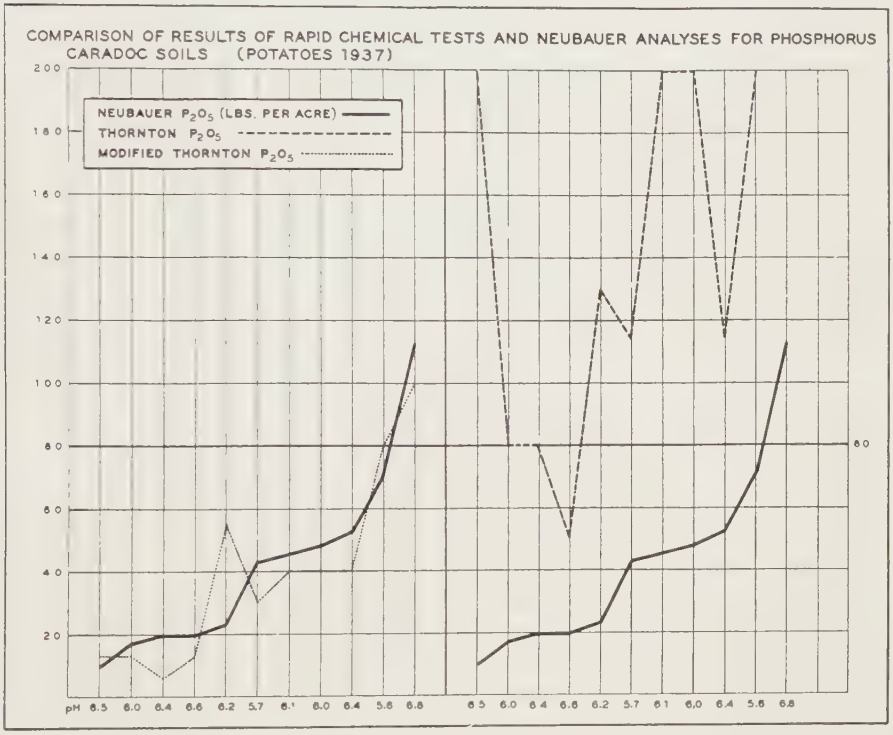

FIGURE 3

potassium deficiency was noted in the crop. The rapid method in this case gives more accurate indications of potassium availability. All 8 soils with Neubauer values below 200 lbs. K_2O per acre showed more or less pronounced symptoms of potassium deficiency, a condition reflected in every case by the rapid test also. Soils above that level, however, are not graded in the same order by the chemical test, and with one exception the latter values are lower. Free carbonates do not appear to influence the results of either method. In general, it may be said that the Thornton method serves fairly well to separate these soils into two groups—those with some degree of potassium deficiency and those apparently well supplied.

In Figure 3, data are given for phosphorus tests on soils of Middlesex County largely devoted to potato culture. On these types the Thornton method has given results much higher than the Neubauer values. The Modified Thornton test, however, gives a very close correlation, and with the exception of one or two minor variations, places the soils in about the same order as the Neubauer rating. It is of interest, that in checking potato tissues, even when the crop had received 750 lbs. per acre of a 4–8–10 fertilizer, doubtful or medium phosphorus tests were obtained, while tissue tests for nitrates and potassium were very high. There would thus appear to be some agreement with the results of the Neubauer method and the Modified rapid test presented in this chart.

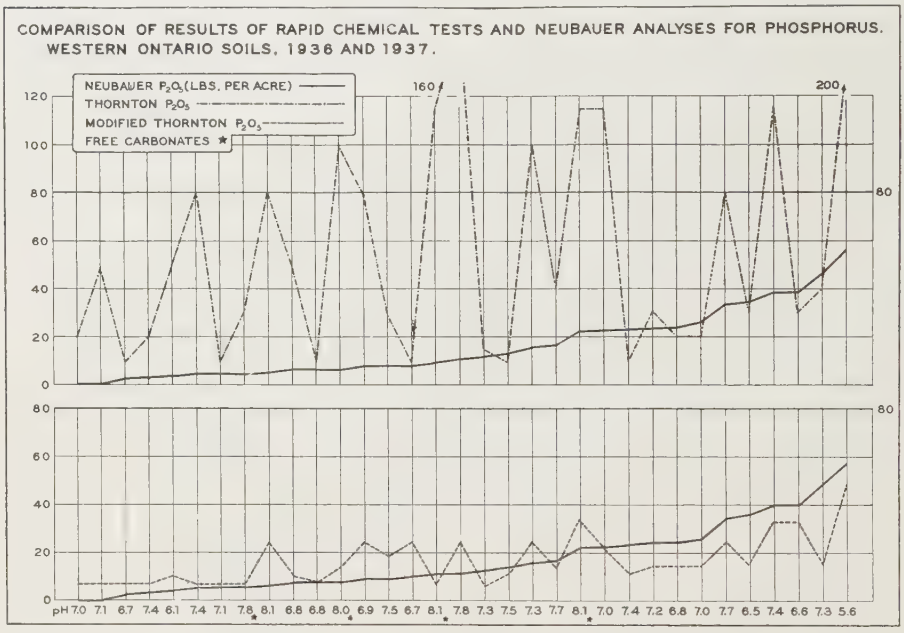

FIGURE 4

The data presented in Figure 4 are for dominant soil types mapped in the Western Ontario soil survey of 1936 and 1937. These samples represent large areas of very important agricultural soils in this part of the Province. Livestock deficiency symptoms are common in dairy herds in Oxford County, on farms on these soil types, a condition reflected by the consistently low Neubauer phosphorus levels. Further, crops grown on these farms give marked response to high phosphate fertilizers. The wide fluctuations in the Thornton test are marked, while the Modified test results agree very closely with the biological method, in spite of the high pH values encountered. That these soils are all somewhat similar in texture and organic matter content possibly explains why the results are more uniform than was the case with the corn soils.

The potassium values for the same group of soils are presented in Figure 5. With a few exceptions, the chemical test has been a very fair index to the available potassium supply. Carbonates apparently are of little influence.

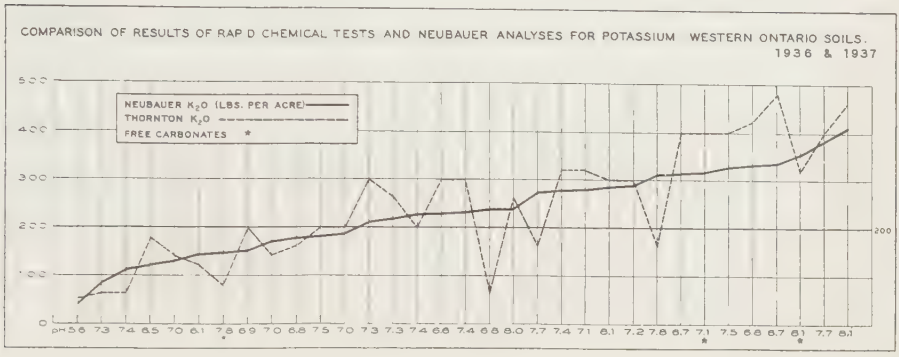

FIGURE 5

In Figure 6 data for phosphorus tests are given for a number of dominant soil types mapped in Central Ontario in 1937. These have been divided according to texture into two groups, the sandy types comprising one group, and the loams and silt loams the second.

In both groups Neubauer data indicate a higher than average phosphorus content, and the range of values is much wider than that found in soils previously considered. As with the sandy soils of the Caradoc area,

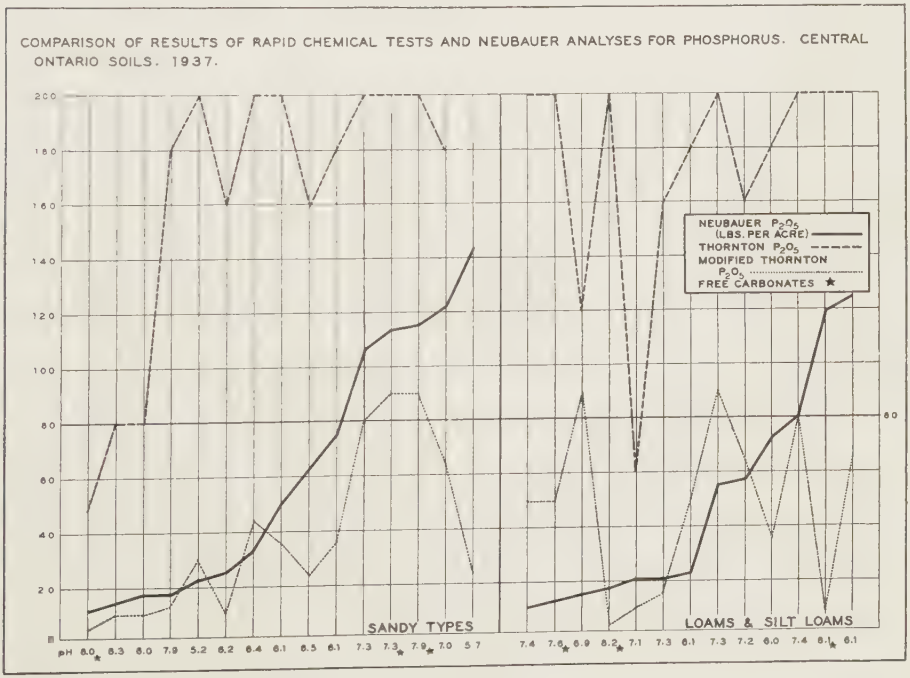

FIGURE 6

the Thornton phosphorus test gives much too high a rating. In the lighter textured soils the Modified method gives results which coincide closely with the Neubauer data for those soils in the deficient class, but fails to properly classify those of a higher rating.

In the case of the loams and silt loams a similar difficulty is encountered with the Thornton test and the Modified test fails almost entirely. There is no correlation with carbonates or pH.

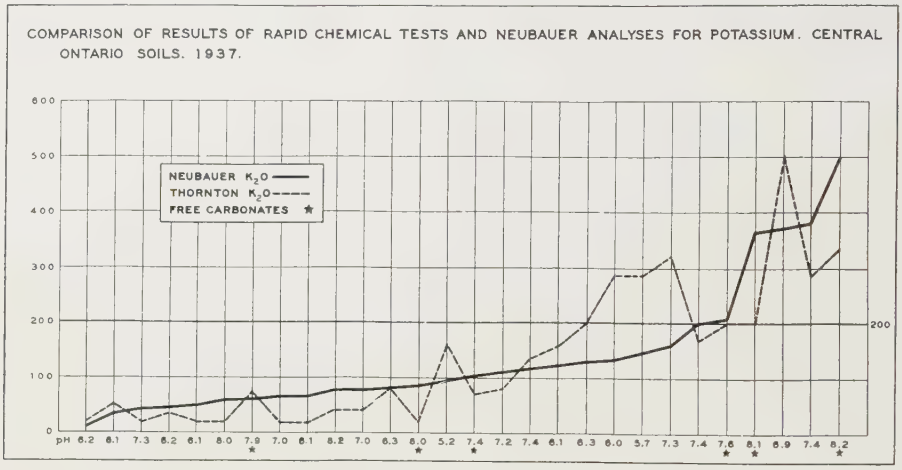

FIGURE 7

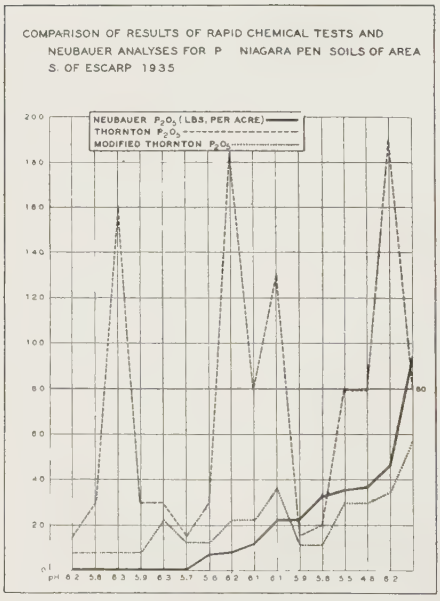

FIGURE 8

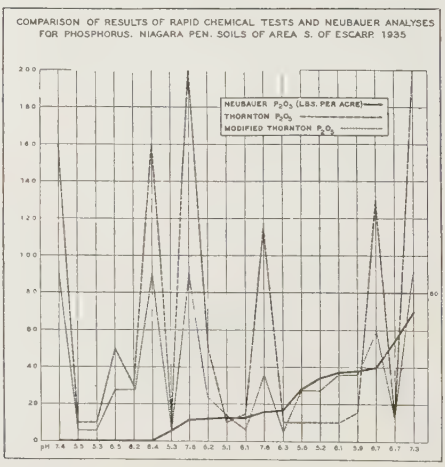

FIGURE 9

The same group of soils is represented as in Figure 6, but no distinction has been made as to texture. The majority of these soils are classed as deficient in potassium by both the biological and chemical methods. In three cases the rapid test has given too high a rating, but in general the correlation may be said to be satisfactory.

Dominant soil types of the Niagara Peninsula, mapped in the soil survey of 1935, are represented in Figures 8, 9 and 10. Again the grouping has been according to texture—sandy types, loams and clays. Low pH values, lack of available phosphorus, and in some cases low organic matter, are characteristic of these soils. Livestock deficiency symptoms are common, and lime and high phosphate applications are necessary for optimum crop production.

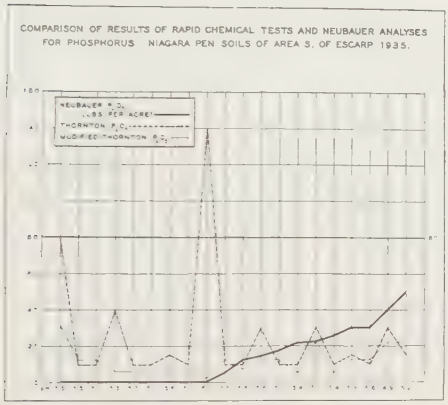

FIGURE 10

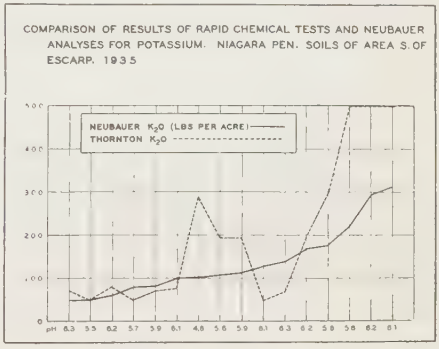

FIGURE 11

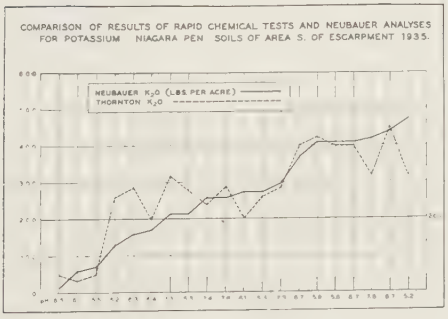

FIGURE 12

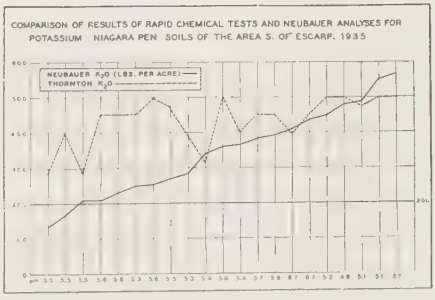

FIGURE 13

The Neubauer values in a large number of cases are extremely low, and generally the method accurately reflects the actual soil conditions with regard to available phosphorus. In the case of the sandy soils, the Thornton test in many instances has given too high a rating, while a very fair degree of correlation with the Neubauer results has been obtained by the Modified method. In the intermediate class neither test agrees particularly well with the Neubauer results, although the Modified test appears slightly more reliable.

In examining Figure 10, lack of phosphorus and low pH values are evident. With one or two exceptions, both chemical tests agree closely with the rye-seedling method.

The results of potassium tests, applied to the same Niagara Peninsula groups, have been plotted in Figures 11, 12 and 13. In the sandy group the rapid test has given results somewhat too high in some cases, but correlates with the Neubauer data fairly well in the intermediate series. The clay soils appear to be well supplied with available potassium, using either the chemical or rye-seedling method as a criterion, but the order of rating differs somewhat. The potassium availability shows no relationship to reaction.

SUMMARY

Preliminary studies of representative Ontario soils of known fertilizer response, by Neubauer analysis, have shown that the method gives a valuable index to the availability of phosphorus and potassium over a wide range of fertility levels.

In the absence of sufficient data from long term fertility experiments, results from Neubauer analyses of a large number of samples of the more important soil types have been utilized as a basis for the calibration of rapid chemical tests for phosphorus and potassium.

Of the several systems of rapid tests proposed, that of Thornton *et al.* has been most widely used by extension workers in this Province, hence has received special attention in this study. The test for phosphorus, while suitable for the acid soils such as are predominant in the Niagara Peninsula, is not generally adapted to the other Ontario soils investigated, probably because of their reaction range.

A modification of the Thornton phosphorus test has been developed, which, for certain groups of soils, gives results correlating much more closely with Neubauer data. When applied to the sandy types of Caradoc Township, the loams of Huron and Oxford Counties, and to the sandy and clay types of the Niagara Peninsula, the agreement with Neubauer results has been very satisfactory. In the case of the sands of Central Ontario, with high available phosphorus, the results are erratic, and with the corn soils and loams and silt loams of both Central Ontario and the Niagara Peninsula, the test fails to classify properly about 30% of the samples. It has been suggested that a high organic matter content may interfere with chemical tests for phosphorus.

Of the various tests for available potassium investigated, that of Thornton is the most satisfactory. With few exceptions it has accurately classified potassium-deficient soils. The results are not always in line with the Neubauer data in the case of an abundant supply, but on the whole the test may be said to cover the normal range of potassium levels quite satisfactorily.

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APPLICATION OF THE NEUBAUER RYE SEEDLING METHOD OF SOIL ANALYSIS TO FERTILITY STUDIES IN ONTARIO[1]

C. P. Rivaz[2]

Ontario Agricultural College, Guelph, Ontario

The principles and applications of the Neubauer system of soil analysis, through the papers of Thornton (5, 6), Dahlberg and Brown (1), Kohnke (2), and others, have probably become sufficiently familiar to those engaged in problems of soil fertility to render unnecessary any further detailed description. In the light of the past year's experience, however, it may be of interest, before presenting any findings, to discuss briefly not only possible sources of error in the procedure, but also certain details of technique which contribute to the saving of time and to uniform and satisfactory results generally. It is realized that some of the phases dealt with have been emphasized by previous workers, and that this presentation may serve but to confirm their findings, nevertheless it is hoped that consideration of the following points may be of some assistance to those who are already using the system, or who contemplate doing so.

MATERIAL AND METHODS

1. *Quality of the Rye Seed.*

The importance of high vitality of the rye seed cannot be overemphasized. Germination must be at least 95%, as well as uniform. The experience has been that slow germination and uneven development of the plants often result in lower absorption of phosphorus. At the commencement of the work it was difficult to procure seed which would meet these requirements. The Rosen variety, recommended by Thornton (6), was available from but one source, in Michigan, and the results obtained with it were at times disappointing, as is illustrated by the following:

Soil	Culture	Germination (1st count)	Germination (Final count)	Mgms. P_2O_5 absorbed	Accepted P_2O_5 value (mean of 2 and 3)
N2	1	*92*	*94*	*0.1*	
	2	99	99	1.9	2.0
	3	95	98	2.1	
N15	1	*89*	*95*	*−0.3*	
	2	95	96	0.9	1.4
	3	97	98	1.8	
Hallman	1	*88*	*95*	*0.8*	
	2	94	100	1.8	2.1
	3	99	99	2.4	
Caradoc 7	1	*92*	*98*	*0.8*	
	2	95	97	2.2	2.3
	3	96	98	2.4	

In September, 1937, a supply of seed was obtained from Kentville, Nova Scotia, known as Cornell 45. Inquiry has revealed that this variety is a line selection made in New York State from a field of what was presumed

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[2] Research Assistant, Department of Chemistry.

to be Rosen rye. This seed, when carefully selected, has proved quite satisfactory in the matter of germination, and generally can be recommended as very suitable for Neubauer work.

2. *Care and Handling of the Seed.*

Neubauer recommends that the seed be stored over quick-lime. A portion of the 1937 crop has been handled according to his recommendations, but to date the germinating qualities have not been tested. The seed being used at present has been stored in small cotton bags in the culture room and has retained its germinating power excellently.

Counting the seed into lots of 100 is a time-consuming and tedious task. To speed up this work a counting board was devised. This consists simply of a small wooden board about 4″ × 8″, with 100 depressions just large enough to accommodate a single rye seed, and of such a depth that the kernel lies completely below the surface. The seed is poured on the board, the surplus swept clear with the hand, then by means of a small pair of tweezers, any depression which has not received a kernel is filled. A few seconds is sufficient to complete the task of counting, with the possibility of error reduced to the minimum. A light metal cover is placed over the board, which is then inverted, and the grain is poured into small envelopes ready for the checking of the weight. Wherever the seed may be stored, it should be placed in the culture room under constant conditions of humidity for some days before weighing, as it has been found that the weight varies with the amount of moisture in the atmosphere. This variation may amount to 1% or about 0.25 mgms. P_2O_5 per 100 seeds. While this is perhaps a small error, it nevertheless should not be overlooked.

3. *Sand.*

Pure washed quartz sand of the following specifications has been used:

20-30 mesh—32% 30-35 mesh—43% 35-50 mesh —24%

It is obtained from the Ottawa Silica Co., Ottawa, Illinois, and is apparently satisfactory, although too prolonged heating in the sterilization process produces a reddish coloration, because of the traces of iron present. This prolonged heating is avoided so that oxidation of the iron is at a minimum.

4. *Sterilization.*

All culture dishes, watering tubes and sand are sterilized by dry heat for 12-15 hours. It has been found that a temperature of 350° F. over this period of time is sufficient.

5. *Seed Treatment.*

As a preventive of mould growth, treatment of the seed with "Semesan" has proved satisfactory, although it has been found that the relative humidity in the culture room is of great influence on the degree of infection. If held over 55%, moulds almost invariably give trouble, but when reduced to 50% little difficulty is encountered, so the practice has been to maintain the relative humidity at 50% ± 5%.

6. *Growing the Plants.*

The seeds are planted vertically by means of forceps, in the sand layer covering the soil-sand mixture. The upper end of each kernel should be about $\frac{1}{8}$″ below the surface. Deeper planting may result in poor germination. Tests have shown that it is unnecessary to place the seed with the

germ-end uppermost. Seed-germinating cabinets have been used by some workers, but at this institution a special culture room, with outside windows, is available for the growth of the plants. The temperature is held at 20° C ± 1° C. by a thermostatically controlled air-conditioning unit. The weight of each dish is checked daily and sufficient water added to take the place of that lost by evaporation. A very sturdy type of seedling, with no tendency to lodge, develops under these conditions. The plants are harvested on the seventeenth day.

7. *Blanks.*

In accepting the Neubauer method, a necessary supposition is that 100 seedlings grown in pure quartz sand alone, will provide suitable 'blank' values for phosphorus and potassium, values which must be subtracted from the results obtained using soil, to indicate the amounts of phosphorus and potassium yielded by the soil in the 17-day growth period. While there has been some criticism of the point, and hesitancy to agree unreservedly with the theory, there nevertheless appears to be no more suitable method of establishing the blank values. The question of the moisture content of the sand blanks has received some attention. Thornton (6) recommends that 60 gms. of water be added rather than 80 gms. as in the case of a soil. The smaller amount of water may induce slightly more uniform germination and be less conducive to mould growth, but the influence on the value for either P_2O_5 or K_2O appears to be negligible. It has been found that the Cornell 45 rye seed used for the past year contains 22.8 to 23.4 mgms. P_2O_5 and 16.1 to 16.6 mgms. K_2O, per 100 seeds, 3.500 gms. in weight. The blank values vary from 21.8 to 22.4 mgms. P_2O_5, and from 15.7 to 16.4 mgms. K_2O, indicating a retention of about 95% of the phosphorus and 98% of the potassium.

8. *Harvesting.*

The harvesting of the seedlings probably requires more care than any other step of the vegetation phase of the Neubauer procedure. The sink should be provided with a faucet for mixing the hot and cold water, so that lukewarm water can be used. The sink is covered with a large metal tray of light galvanized iron, about 18″ × 24″, and 1½″ in depth. In the centre of the tray is soldered a zinc screen, 9″ × 12″, with circular openings about 2 mm. in diameter. A circular brass 2 mm. sieve is used also, so that the wash water must pass through two screens. Most of the rootlets which may break off are held in the first sieve, but the second screen in the tray serves as an extra precaution. After thoroughly washing the roots by gentle manipulation and repeated rinsing, all fine root hairs on the screens are carefully removed by means of fine tweezers. Heavy clay soils are the most difficult to handle in the harvesting operation, and here great care must be exercised, otherwise the root-mass may be badly broken up, with consequent danger of loss of rootlets.

9. *Drying and Ashing.*

The shoots are cut from the root system in the process of washing. They are cut once more and placed in the original culture dish, with the root mass and any free seed coats or ungerminated seeds placed over them. The dishes are allowed to dry in a dust-free room, preferably the culture room, for 36 to 48 hours, when the contents are transferred to large crucibles and dried at 60° for 4 to 5 hours. The drying temperature should not be

higher unless the plants are well air-dried first. If allowed to air-dry for 72 to 96 hours, the oven temperature may be increased to 100° and the time reduced to one hour. After removing from the oven, it is well to make sure that the mass is not adhering to the crucible, if stains are to be avoided in the ashing procedure. This procedure has been standardized and is carried out as follows: The crucibles are placed in the cold muffle with the door completely closed. After a period of 20 to 25 minutes smoking ceases and the temperature reaches 600°. The door is then opened about $\frac{3}{4}''$ to allow access of air, and the ashing is continued for 30 to 35 minutes longer, then the position of the crucibles is reversed. With the door still slightly open, the heating is continued for another hour, making the total time of ashing two hours.

10. *Preparation of the Solution for Analysis.*

After cooling, the crucibles are removed from the muffle and covered with watch glasses; 2 to 3 ml. of water are carefully added, raising one edge of the glass only, as a precaution against mechanical loss during the slaking. After a few minutes the glasses are washed and water is added to the crucibles to a depth of about $\frac{1}{2}''$. Upon the addition of 4 ml. of HCl, the contents are evaporated to dryness on the steam bath to render the silica insoluble. About the same amount of warm water, and 2 to 3 ml. of HCl are again added and the crucibles placed on the bath until solution of the phosphoric acid is complete, when the contents are transferred without filtering to a 100 ml. volumetric flask, using a rubber tipped glass rod for loosening and working up the insoluble residue. The contents of the flask are cooled to 20°, made up to the mark, and filtered through folded filters into glass stoppered bottles for analysis.

11. *Determination of P_2O_5.*

The method for P_2O_5 determination which has been adopted is a modification, developed at Purdue University, of the Official Volumetric Method. Precipitation of the ammonium phosphomolybdate is carried out at room temperature, with the aid of continuous shaking for one-half hour on a special shaking machine. The normality of the NaOH, 0.1313 N, is not exactly that which would be used were it calculated on the basis of the equation:

$$2\ (NH_4)_3PO_4 \cdot 12\ MoO_3 + 46\ NaOH = 2\ (NH_4)_2HPO_4 + (NH_4)_2MoO_4 + 23\ Na_2MoO_4 + 22\ H_2O,$$

but rather is based on recovery of phosphorus from rock phosphate sample No. 56 of the U.S. Bureau of Standards. Using a 20 ml. aliquot, 1 ml. of 0.1313 N NaOH is equivalent to 2.0 mgms. P_2O_5 per 100 gms. of soil. This procedure has proved very reliable in the Neubauer analysis, so that with the usual precautions in technique no difficulty is experienced in obtaining perfect duplicate results. It is not considered necessary to make more than one P_2O_5 determination per culture. The maximum variation allowed between duplicate cultures is 1 mgm. P_2O_5. A difference greater than 1 mgm. means that the results cannot be accepted. In this connection, it should be pointed out that the P_2O_5 content of 100 seeds before planting may vary as much as 1 mgm. Careful analyses of random lots of 100 seeds, 3.500 gms. in weight, have revealed that this may be the case, although usually such results show no greater variation than 0.5 mgm. P_2O_5. With the Cornell 45 rye seed used during the past season, for about 65% of the soils tested, the P_2O_5 content of duplicate cultures varied no more than 0.5 mgms.

12. *Determination of K_2O.*

The potash analysis is carried out according to the Official Method (Lindo-Gladding), using $PtCl_4$ as the precipitant.

Precipitation of Ca, Fe, Etc.

Forty ml. of solution are pipetted into a 100 ml. volumetric flask, and 5 ml. of NH_4OH and 5 ml. of a saturated solution of NH_4 oxalate are added. The flasks are heated to boiling on a hot plate, cooled, allowed to stand overnight and made up to the mark. After filtering, a 40 c.c. aliquot is pipetted into an evaporating dish containing 2 ml. of 1 : 1 H_2SO_4. Platinum dishes are preferable, but on account of the cost fused silica dishes (Vitreosil) have been substituted. The dishes are placed on a steam bath after the addition of about 0.1 gm. of sucrose (to aid ignition later) and evaporation is carried on until the black, syrupy mass almost solidifies. The dishes are then ignited on a Purdue burner. In the initial heating, the syrup may swell from the bottom of the dish, but spattering does not occur. The ignition is completed over a Méker burner.

In using the silica dishes, difficulty is sometimes encountered in obtaining a perfectly white residue. If this occurs it is taken up in a little dilute HC1 and filtered on a specially designed microfilter, using suction. The volume of the filtrate and washings, which are transferred back to the original dish, should not exceed 25-30 ml.; 1 ml. of $PtC1_4$ is added (0.1 gm. Pt. per ml.), and the determination of K_2O made according to the Lindo-Gladding procedure. The factor 1.21 converts the weight of K_2PtCl_6 to mgms. K_2O per 100 gms. of soil. The difference between duplicate cultures should not exceed 2.0 mgms.

APPLICATION OF THE METHOD

Since the inception of the Neubauer work at this institution in May 1937, the method has been employed in studies of numerous fertility problems. Some of the results have already been reported in connection with standardizing rapid chemical tests. Also, in a general way, in the recent paper of Morwick and Heeg (3), showing the relationship between chemical characteristics of some Ontario soils, and their geological origin, average Neubauer values obtained for representative samples have been compared with data obtained by chemical analyses. As further indication of what may be characteristic of certain soil types, some of the more typical Neubauer results are presented in greater detail.

Values obtained for the sandy potato soils of Middlesex County have also been included as well as data covering the fertility level of an area generally considered one of the most productive of the Province, namely, the southwestern Peninsula, consisting of the Counties of Essex and Kent. The majority of these samples, including a few from Lambton, Huron and Middlesex Counties, were collected by the author in connection with sugar beet studies, but they are representative of the soils on which, besides sugar beets, such crops as corn, tomatoes, beans and burley tobacco are successfully grown. The results for this group have been given first, in Table 1. Included also are a number of the soils from the same district (N series), used in the rapid test calibration mentioned previously.

TABLE 1.—NEUBAUER VALUES FOR SOME TYPICAL CULTIVATED SOILS OF SOUTHWESTERN ONTARIO

Soil No.	Soil type	Township	County	pH	Lbs. per ac.	
					P_2O_5	K_2O
9a	Brookston clay	W. Tilbury	Essex	6.3	80	866
33a	" "	E. "	Kent	6.6	76	732
36a	" "	E. "	Kent	6.9	52	810
37a	" "	E. "	Kent	6.6	106	1,016
59a	" "	E. "	Kent	7.0	106	1,156
59b	Subsoil	E. "	Kent	—	40	624
	Average of 5 surface samples				83	896
1a	Brookston clay loam	Dover	Kent	7.0	90	278
62a	" " "	Rochester	Essex	7.0	60	890
62b	Subsoil			—	44	764
63a	Brookston clay loam	Mosa	Middlesex	6.5	44	426
63b	Subsoil			—	0	450
65a	Brookston clay loam	Dover	Kent	7.0	170	1,106
N1a	" " "	Dover	Kent	6.6	70	548
N17a	" " "	Howard	Kent	6.6	34	774
N17b	Subsoil			—	20	556
N29a	Brookston clay loam	Rochester	Essex	6.2	94	674
N29b	Subsoil			—	18	448
N31b	Brookston clay loam	Raleigh	Kent	7.0	40	204
N31b	Subsoil			—	18	222
N33a	Brookston clay loam	Dover	Kent	6.6	38	716
N33b	Subsoil			—	28	584
31a	Brookston silt loam	Maidstone	Essex	6.3	26	278
53a	" " "	Ekfrid	Middlesex	7.5	64	310
	Average of 11 surface samples			—	64	564
	Average of 6 subsoil samples			—	21	504
23a	Brookston sandy loam	Harwich	Kent	6.7	58	484
60a	" " "	Camden	Kent	7.2	32	564
60b	Subsoil			—	30	404
N21a	Brookston sandy loam	Harwich	Kent	7.0	36	610
N21b	Subsoil			—	16	520
	Average of 3 surface samples			—	42	552
6a	Clyde clay	Dover	Kent	7.9	72	290
N35a	" "	Dover	Kent	7.2	42	552
N35b	Subsoil			—	10	520
21a	Clyde silt loam	Raleigh	Kent	6.9	64	476
47a	" " "	E. Dover	Kent	7.8	64	254
48a	" " "	E. Dover	Kent	7.9	38	302
49a	" " "	E. Dover	Kent	7.8	90	388
64a	" " "	E. Dover	Kent	7.8	54	362
64b	Subsoil			—	0	220
	Average of 5 surface soils			—	58	356
5a	Thames clay loam	Dover	Kent	8.0	38	510
61a	" " "	Chatham	Kent	7.4	54	548
61b	Subsoil			—	40	582
42a	Berrien sand	Brook	Lambton	6.8	32	452
N15a	Burford loam	Howard	Kent	5.6	28	84
N15b	Subsoil			—	0	0
N19a	Perth clay loam	Harwich	Kent	7.0	32	220
N19b	Subsoil			—	8	148
N23a	Granby sand ?	Colchester	Essex	7.0	28	136
N23b	Subsoil			—	16	12
N25a	Granby sand ?	Colchester	Essex	7.4	32	12
N25b	Subsoil			—	18	0
N27a	Clyde loam ?	Colchester	Essex	6.2	206	1,014
N28a	Subsoil			—	34	696

Discussion of Table 1.

The Brookston and Clyde series, which predominate, are characterized by poor natural drainage, high organic matter content, a slightly acid to alkaline reaction, and abundance of replaceable calcium and magnesium. Chemical studies have also indicated that they are well supplied with replaceable potassium, but that the readily-soluble phosphorus content is quite variable, indications which the Neubauer analysis tends to confirm. By the rye seedling method, the minimum amounts of P_2O_5 and K_2O tentatively considered necessary for sufficiency (for the common crops such as grain and corn) are 80 and 200 lbs. per acre, respectively. The K_2O levels of the 37 Brookston and Clyde soils examined are all above the minimum; 23 samples contain between 500 and 1,200 pounds per acre. The P_2O_5 supply, on the other hand, is usually less than the minimum requirement, for only 7 soils contain 80 lbs. or more. A small number of subsoils have also been examined, mostly those of the heavier types; they are lower in phosphorus than the corresponding surface samples but contain only a little less potassium.

Although very productive, these soils generally show marked response to phosphate fertilization, and in the case of sugar beets, fertilizer mixtures comparatively high in phosphorus have proved very satisfactory. The number of samples is too small to allow the drawing of very definite conclusions, but it might be pointed out that the Clyde silt loams on the average, are lower in Neubauer potassium than the other major soil types. This is substantiated by field experience, for it has been recognized for some time that an increase in the potassium content of sugar beet fertilizers is advisable for this soil.

Represented in the latter part of the table are a miscellaneous group of soils occurring less frequently in this district. Some of the lighter textured samples are quite low in both phosphorus and potassium. They differ somewhat from the dominant soil types in geological origin, having been formed from outwash material rather than sedimentary deposits.

TABLE 2.—NEUBAUER VALUES FOR THE SANDY SOILS OF MIDDLESEX COUNTY DEVOTED TO POTATOES

Soil No.	Soil type	Township	pH	Lbs. per ac.	
				P_2O_5	K_2O
3a	Berrien Sand	Metcalfe	6.4	52	77
3b	Subsoil	"	6.8	26	34
9a	Berrien Sand	"	6.5	10	60
9b	Subsoil		6.2	0	25
13a	Fox fine sandy loam	Caradoc	5.7	44	128
13b	Subsoil	"	6.2	16	87
15a	Fox fine sandy loam	"	6.4	20	209
15b	Subsoil		6.2	0	98
21a	Fox fine sandy loam	"	6.0	18	178
21b	Subsoil		5.6	16	39
25a	Fox fine sandy loam	"	6.2	24	70
25b	Subsoil	"	6.4	16	74
31a	Fox sandy loam	"	6.8	112	230
31b	Subsoil		6.6	24	47
37a	Fox fine sandy loam	"	6.6	20	193
37b	Subsoil		6.9	12	217
	Average of 8 surface samples		—	38	168
	Average of 8 subsoil samples		—	14	78

Discussion of Table 2.

The results given in Table 2 were obtained with soils of the Fox and Berrien series, in Caradoc and Metcalfe townships, Middlesex County. These samples were taken in conjunction with fertility experiments with potatoes, from the untreated or check plots, and are representative of the soils of the district commonly devoted to this crop. They range in texture from a fine sand to a sandy loam. Levels of both phosphorus and potassium are in most cases quite low, especially in the subsoil. As might be expected, the lowest potassium levels occur in the sands.

TABLE 3.—NEUBAUER VALUES FOR SOILS OF THE NIAGARA PENINSULA SOUTH OF THE ESCARPMENT

Soil No.	Soil type	Township	County	pH	Lbs. per ac.	
					P_2O_5	K_2O
129	Fonthill loam	Stamford	Welland	6.2	11	66
64		Pelham	"	5.9	34	85
104		"	"	6.2	96	298
	Average of 3 samples			—	47	150
57	Brantford clay loam	Ancaster	Wentworth	7.6	16	420
158		"	"	6.1	37	276
58		"	"	6.7	54	374
	Average of 4 samples			—	38	370
138	Berrien sandy loam	Moulton	Haldimand	6.3	0	49
70		Thorold	Welland	5.8	0	176
59		Ancaster	Wentworth	6.1	22	316
	Average of 4 samples			—	6	180
75	Caistor clay loam (silt knolls)	Wainfleet	Welland	5.5	0	73
21		S. Grimsby	Lincoln	5.3	6	218
85		Wainfleet	Welland	6.1	14	60
	Average of 4 samples			—	5	156
50	Pelham sandy loam	Pelham	Welland	5.6	7	112
65		"	"	5.8	36	224
51		"	"	4.8	44	106
	Average of 4 samples			—	31	123
121	Jeddo Clay	Humberstone	Welland	5.5	0	166
108		"	"	5.1	23	552
23		N. Grimsby	Lincoln	5.3	29	288
	Average of 3 samples			—	17	202
106	Niagara clay	Willoughby	Welland	5.1	0	470
119		Crowland	"	5.5	0	278
116		Willoughby	"	5.2	50	446
	Average of 3 samples			—	17	398
18	Haldimand clay	Gainsborough	Lincoln	5.0	0	366
146		Rainham	Haldimand	5.8	12	397
13		Caistor	Lincoln	4.9	39	486
	Average of 8 samples			—	14	378
36	Oneida clay loam	Clinton	Lincoln	5.1	13	218
66		"	"	6.3	17	161
149		Cayuga N.	Haldimand	5.2	34	476
	Average of 4 samples			—	23	318
93	Wauseon sandy loam	Wainfleet	Welland	5.9	0	113
33		"	"	5.7	6	80
32		"	"	6.1	22	102
	Average of 4 samples			—	7	110
109	Welland clay	Humberstone	Welland	5.5	0	138
125		Wainfleet	"	5.6	14	230
42		Bertie	"	5.4	22	372
	Average of 5 samples			—	6	240

Discussion of Table 3.

The soils represented in Tables 3, 4 and 5 were mapped in the soil survey of 1935, 1936 and 1937, respectively. In each case Neubauer values considered typical of a particular soil type are recorded, as well as the mean values for all samples analyzed. The results are comparable in that the samples were all taken from grasslands and pasture lands which had received no recent fertilizer or manurial treatment. Under these conditions it is to be expected that the levels of available nutrients have more or less reached an equilibrium, so that any differences found are a result of inherent differences in the soils themselves, rather than of fertilizing and cropping practices. The general characteristics of these groups have already been emphasized (3), so comment at this time will be confined chiefly to the individual types of each group.

The data in Table 3 cover the important soils of that part of the Niagara Peninsula south of the Escarpment, characterized by distinctly low pH values. It is evident that the clays and clay loams in practically all cases are very low in available phosphorus, but on the whole are quite well supplied with potassium. All samples tested, of the Haldimand, Niagara and Brantford series, have given K_2O values above 200 pounds per acre, ranging up to about 500 pounds. The samples of the Berrien and Wauseon series are very low in phosphorus, and the potassium is lower than in the heavier types. The Fonthill and Pelham soils are also rather low in potassium, but the phosphorus is higher.

Table 4.—Neubauer values for the dominant soil types of Oxford, Huron, Middlesex and Perth Counties

Soil No.	Soil type	Township	County	pH	Lbs. per ac.	
					P_2O_5	K_2O
73M	Guelph loam	Oxford E.	Oxford	7.4	3	110
94		Colborne	Huron	8.1	21	412
182		London	Middlesex	7.4	38	274
	Average of 9 samples			—	17	250
159	Huron clay loam	Ashfield	Huron	6.8	8	184
139		Usborne	"	8.1	11	356
72		Williams E.	Middlesex	7.3	46	226
	Average of 10 samples			—	14	244
105	London loam	McKillop	Huron	8.1	6	286
136		Blanshard	Perth	7.5	9	152
172		London	Middlesex	6.8	22	336
	Average of 7 samples			—	13	270
34	Perth clay loam	Hibbert	Perth	7.8	5	146
144		Stephen	Huron	7.5	14	186
64M		Oxford E.	Oxford	7.5	32	272
	Average of 6 samples			—	16	210

TABLE 5.—NEUBAUER VALUES FOR THE DOMINANT SOIL TYPES OF DURHAM AND NORTHUMBERLAND COUNTIES

Soil No.	Soil type	Township	County	pH	Lbs. per ac.	
					P_2O_5	K_2O
71H	Brighton sand	Haldimand	Northumberland	6.3	15	80
1H		Cramahe	"	6.1	76	34
86H		Brighton	"	7.3	106	162
	Average of 6 samples			—	65	73
69H	Newcastle loam	Brighton	Northumberland	6.9	16	372
100H		Clarke	Durham	7.2	58	114
5H		Murray	"	6.1	124	128
	Average of 4 samples			—	70	249
83H	Dundonald sandy loam	Haldimand	Northumberland	6.0	18	48
23H		Murray	"	6.5	65	78
51H		Cramahe	"	7.4	113	104
	Average of 6 samples			—	81	78
108H	Bondhead loam	Brighton	Northumberland	7.3	22	42
20H		Murray	"	7.3	56	120
58H		Percy	"	6.0	73	134
	Average of 5 samples			—	40	82
65H	Newcastle silt loam	Percy	Northumberland	7.4	12	200
73H		Hamilton	"	7.6	14	208
18H		Murray	"	8.1	119	364
	Average of 4 samples			—	40	318
77H	Tecumseh sandy loam	Hope	Durham	7.9	12	88
53H		Brighton	Northumberland	7.9	18	58
15H		Murray	"	6.4	35	132
	Average of 3 samples			—	22	93

Discussion of Tables 4 and 5.

Representative Neubauer values for the dominant soil types of Oxford, Huron, Middlesex and Perth counties are given in Table 4. The phosphorus levels are definitely low, and the potassium levels variable. The rye seedling method indicates that in many cases the available potassium supply of these soils is approaching the lower limit of sufficiency (200 pounds per acre), if not already below it. There is no marked difference in the nutrient supply of the four soil types represented.

Something of the characteristics of important Central Ontario soils is indicated in Table 5. The phosphorus levels on the average are higher than for the soils just discussed, although in some cases there is considerable variation between samples of the same group. The potassium values are variable, but tend to be related to texture. On the whole, these soils tend to be lower in potassium than either the Niagara or Western Ontario group.

SUMMARY

1. Recent experience with the Neubauer system of soil analysis has served to re-emphasize that special precautions are necessary in certain steps of the vegetative and analytical phases of the work. Vitality of the seed, depth of planting, relative humidity of the atmosphere in the culture

room and care in harvesting are particularly important. It is considered that the use of suitable seed, of uniform germination, contributes more than any other single factor to the success of the method.

2. A suitably controlled electric muffle is recommended for the ashing of the dried plant material. The modified volumetric method for phosphorus determination, using a mechanical shaker to aid precipitation, when carefully standardized, is simple, rapid and accurate. While the potassium analysis is rather tedious, the procedure described has been simplified as much as possible, without sacrifice of accuracy.

3. Results of the Neubauer analysis, obtained with soils from various parts of Ontario, have been presented. The soils of Kent and Essex Counties, noted for their general productivity, appear to be lacking more in phosphorus than in potassium. Levels of the latter, especially in the heavier Brookston and Clyde types, may be several times greater than the minimum level of 200 pounds per acre K_2O. The sandy potato soils of Middlesex County are low in both phosphorus and potassium, emphasizing the difficulty experienced in maintaining high fertility levels in soils of coarser texture.

4. Representative Neubauer data obtained on grass and pasture land soils sampled in the Ontario Soil Survey, give an indication of the variations in fertility level which may be encountered in samples of the same soil type. While in some instances these variations may be wide, the individual types in most cases appear to possess rather definite fertility characteristics.

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FUNDAMENTAL STUDIES OF THE NEUBAUER PLANT SEEDLING METHOD FOR THE DETERMINATION OF THE ROOT-SOLUBLE PHOSPHORUS IN SOILS[1]

I. Motzok[2]
Ontario Agricultural College, Guelph, Ontario

INTRODUCTION

In recent years the general recognition that chemical tests of the soil are not completely satisfactory in measuring the amount of available plant food has resulted in the development of a number of biological methods which assign to the plants themselves the task of evaluating the availability of nutrients in the soil. Because of the amount of time and expense involved the old methods of pot cultures and field experiments are not practical for an extensive survey of soils. To serve this need a number of more rapid and relatively inexpensive biological methods have been developed. The procedure devised by Neubauer (11) is showing great promise in the estimation of root-soluble phosphorus and potassium, and has already received a wide application in fertilizer advisory work in Germany.

The Petkuser variety of rye which Neubauer uses and recommends is not grown to any extent in America. In retaining the use of rye seedlings as the extracting agents, Thornton selected Rosen rye, which over a period of 5 years has proved to be very satisfactory. In comparative work, however, he[3] stressed the use of the same variety of seed in all co-operating laboratories. These recommendations are in agreement with the findings of Opitz and Benade (12), Densch (2), and others, who noted marked differences in the extracting power of different varieties of the seed.

Rye is a staple crop in Germany and a dependable source of high quality seed can be relied upon. On this continent, however, rye is grown in relatively small quantities, and crop failures of specific varieties are not infrequent.

Fudge (4) had to use wheat because at the time it was impossible to obtain rye that would give the high germination required for accurate work.

In 1937 at the Neubauer laboratory at the Ontario Agricultural College it was found that the only sample of Rosen rye obtainable frequently gave poor germination, and its use had to be discontinued in favour of another variety, Cornell 45.

The suitability of other species of plants for this method, in comparison with rye, has been studied by Neubauer (11), Kruppa (8), Lohse (9) Schumann (16), and others. A review of their findings would indicate that the relative absorption capacities of the different species varied with such factors as pH of the soil, fertilizer treatments, soil type and the like. It is also evident that in the quantities extracted there is a greater variation between the different species than between the different varieties of the same species of plant.

[1] Part of a thesis submitted to the Faculty of the School of Graduate Studies of the University of Toronto, in partial fulfilment of the requirements for the degree of Master of Science in Agriculture, May 1938, and presented at the meeting of the Soils Group of the Canadian Society of Technical Agriculturists, held at the American Association for the Advancement of Science convention at Ottawa, Canada, June 23, 1938.

[2] Research Assistant.

[3] Private communication to the Department of Chemistry, Ontario Agricultural College.

Lohse (9), Schumann (16), and others have shown that the normal vegetation period of rye in the Neubauer cultures is from 15 to 17 days, when the seedlings show clear sign of lack of food. The wheat, oats and barley, however, grew for 18 and 19 days before any deficiency symptoms could be observed.

In the light of the present investigation, a summary of the literature would indicate that the reliable supply of high quality seed, and the shorter vegetation period of the seedlings were the important factors in the choice of rye as a suitable extracting agent in Neubauer's seedling method of soil analysis.

MATERIAL AND METHODS

The details of this rye seedling technique are fully described by the originators, Neubauer and Schneider (11), and also by Fudge (4), Thornton (19), and others. The phosphorus determinations were made by the so-called ceruleomolybdate blue colorimetric procedure proposed by King (7), who modified the methods developed by Fiske and Subbarow (3) and Martland and Robison (10).

This project was conducted for the purpose of finding an extracting agent more adaptable and efficient than the rye in the Neubauer method of determining the root-soluble phosphorus in the soil. These studies were extended to include a comparison of the relative absorption capacities of three varieties of rye: Rosen rye used by Thornton, Cornell 45 used in the laboratory at the Ontario Agricultural College, and Petkuser rye used and recommended by Neubauer.

I. PRELIMINARY EXPERIMENTS

Spring Wheat.

Swanson (18) has discussed the influence of climate, especially rainfall, on the formation of starchy and corneous kernels in wheat. The short and dry growing season of the western provinces produces spring wheat that is very uniform in quality having none of the characteristics of heterogeneous starch and corneous kernels that are inherent in the winter wheat grown in Ontario.

The variety Reward, chosen for this investigation gave very satisfactory germination, and the root development was more extensive than that of the rye, indicating a more complete penetration of the soil in the culture dishes.

Preliminary investigations being very satisfactory and indicating the possibility of its adaptability in the Neubauer technique, the initial experiments were expanded and the results are included in the detailed study which constituted the major part of this investigation.

Winter Wheat.

Experiments with the variety Dawson's Golden Chaff, commonly grown in Ontario, have indicated that corneous kernels tend to be heavier than starchy ones of approximately the same size, and that the phosphorus absorption by the corneous grain was somewhat greater than that by the starchy type. The differences noted would indicate the necessity of a very careful selection of seed if accurate results are to be obtained. This tedious and time-consuming process would practically eliminate the Dawson's wheat as a suitable biological agent in the Neubauer technique

Oats and Barley.

Preliminary tests were carried out with two varieties of oats, Banner and Erban, and one variety of barley, O.A.C. 21.

Although the germination in these experiments was satisfactory, the presence of the hull covering the germ of the seed may be a limiting factor in the selection of grain for high germination quality. The hull also adds bulk to the grain, a factor which may influence the initial phosphorus content, as well as the kernel weight of the seed.

Buckwheat.

Silver hull buckwheat was used in a series of cultures similar to the other preliminary experiments. Buckwheat is a cotyledonous plant which lifts its seed coats out of the soil, and as the leaves develop the seed coats drop off. Some of the seedlings near the edge of the dish often deposit their seed coats outside the vessel, and as it would be necessary to include or exclude all the seed coats in the analysis of each culture, the technique may offer particular difficulty in obtaining accurate results.

Lettuce.

The Grand Rapids variety gave very good germination, but the growth of the plants and development of the roots were very poor. It would appear that the adaptability of such a species of plant would necessitate some modification of the regular Neubauer procedure.

II. PHOSPHORUS ABSORPTIONS BY REWARD WHEAT AND CORNELL RYE

The use of the sand blank in the estimation of nutrient absorption is made on the assumption that similar losses occur in the soil cultures as in the sand. The significance of this assumption was discussed by Stewart (17), and it is evident in the fact that 100 rye seeds weighing 4.0 grams, and containing approximately 25 mg. P_2O_5, may lose in the sand culture as high as 10% of the total phosphorus content of the seed. The seedlings usually extract 0–10 mg. P_2O_5 from 100 grams of soil, and the determination of this absorption with any degree of accuracy is dependent on a reliable estimation of the seed blank.

Prevot and Stewart (13) have pointed out that in the roots of barley seedlings in water culture, the potential absorption surface is greatest at the tip and extends back in a gradual decline to the place where secondary roots appear. The meristematic tissue in the root tips contains a relatively large amount of phosphorus necessary for cell division, and it is possible that some of the losses of phosphorus from the seedlings in the sand cultures may be the result of the washing away of the delicate root tips and fine root hairs during the process of harvesting of the plants.

Pugh (14), Scarseth (15) and others have shown that alumino-silicate colloids have the property of sorbing phosphate ions, and that the phosphate retention was greatly increased when the alumino-silicate was enriched with iron. The quartz sand used in the sand cultures of these experiments, when heated over-night, took on a light reddish colour, indicating the probable change of some of the iron from the complex alumino-silicate compound to the oxide form, which in water may have a slight tendency to form highly sorptive hydrous iron oxide colloids. It is possible that the

mechanism of anion absorption in the semi-permeable membrane of the root cells is reversed by the sorptive pressure set up by the iron and aluminosilicate colloids, and may result in a negative migration of the anions from the plant to the culture medium. The percentage of sorptive colloids in the sand may be relatively very small, but the actual amount may be sufficient to account for some of the losses of phosphate ions from the plant.

In this connection Stewart (17) has noted that some soils with the seedling method show negative values for the root-soluble P_2O_5, that is to say, the seedlings grown in the soil contained less phosphorus than those in sand cultures. Gracanin (6) discussed the significance of these negative values and stated that they occur with soils exceedingly low in available P_2O_5 and possessing high absorption capacities.

(*a*) *Blank Values of Cornell 45 Rye and Reward Wheat.*

A series of sand cultures was conducted with the rye and the wheat to determine the P_2O_5 content of the seedlings in the estimation of the blank value for these two grains.

TABLE 1.—P_2O_5 CONTENT OF 100 GRAIN LOTS OF CORNELL 45 RYE WEIGHING 3.5 GRAMS

No.	Date	Mg. P_2O_5	No.	Date	Mg. P_2O_5
1	Nov. 23	22.9	7	Feb. 15	21.9
2	" 23	21.8	8	" 15	23.4
3	" 23	23.4	9	" 15	23.0
4	" 23	22.4	10	" 15	22.8
5	" 23	23.4	11	" 15	22.7
6	" 23	22.9	12	" 15	22.4
	Average	22.8		Average	22.7

General average 22.75 mg.

TABLE 2.—P_2O_5 CONTENT OF 100 GRAIN LOTS OF CORNELL RYE 45 GROWN IN SAND FOR 17 DAYS

(3.5 gm. per 100 kernels)

No.	Date	Mg. P_2O_5	No.	Date	Mg. P_2O_5	No.	Date	Mg. P_2O_5
1	Nov. 20	22.4	5	Jan. 27	23.0	9	Feb. 28	21.4
2	" 20	22.6	6	" 27	22.9	10	" 28	21.4
3	" 20	23.0	7	" 27	22.3	11	" 28	21.3
4	" 20	22.8	8	" 27	21.8	12	" 28	21.5
	Average	22.7		Average	22.5		Average	21.4

The data given in Tables 1 and 2 show considerable variation in the P_2O_5 content of the ungerminated rye seed, as well as the seedling plants grown in sand. It is possible that the heterogeneous genetic complexity of the rye may be partly or wholly responsible for these variations.

The P_2O_5 contents of the ungerminated wheat and the sand culture seedlings at four stages of vegetation, given in Table 3, indicate that the major losses of P_2O_5 took place between the 9th and the 12th day of vegetation, and only slight losses are evident before and after this period. No marked differences are to be noted in the losses of P_2O_5 from the roots and from the stalks.

In contrast to the rye, no significant variations are evident in the P_2O_5 content of the individual cultures at any one stage of growth, and the normal vegetation period appeared to be much shorter than that of the rye. Excessive lodging usually took place on about the 12th day, and was followed by slow wilting of the plants and a browning of the roots, showing distinct senescence at the 15th day of vegetation.

(*b*) *Influence of the Length of Vegetation Period on the P_2O_5 Absorption by Reward Wheat and a Comparison with the Absorption by Cornell Rye.*

The suitability of Reward wheat for the Neubauer seedling culture method was studied on the following soils:

1. Fox sandy loam—pH5.7.

2. Bondhead loam—pH 7.0.

3. Welland clay I—taken from one of a series of permanent fertility plots located in the heavy clay area in Welland County, Ontario. Over a period of 15 years this plot received 6 applications of 20% Superphosphate at the rate of 320 lbs. per acre and 3 applications of manure at the rate of 10 tons per acre. The pH of the soil was 6.0.

4. Welland clay II—A sample taken from the check plot of the series mentioned above. This plot has had only the manure treatment similar to that of plot 1; the pH of the soil was 4.6.

Since the seedlings of the wheat lodged excessively on about the 12th day, two vegetation periods, 12 and 15 days, were studied. Blank values of corresponding vegetation periods were used in the estimation of P_2O_5 absorption. Neubauer values for these soils were determined in the usual manner by growing Cornell 45 rye for 17 days and estimating the assimilations of P_2O_5 in mg. per 100 grams of soil.

TABLE 3.—EFFECT OF LENGTH OF VEGETATION PERIOD ON THE P_2O_5 CONTENT OF ROOTS AND STALKS[1] AND OF THE WHOLE PLANTS OF REWARD WHEAT[2] GROWN IN SAND

Vegetation period in days	P_2O_5 in mg.			
	Roots	Stalks	Whole plant	Blank value
6	—	—	46.5	
6	—	—	46.4	
6	—	—	46.5	
9	5.6	40.8	46.4	
9	5.6	40.7	46.3	
9	—	—	46.3	
9	—	—	46.4	
12	4.9	40.1	45.0	
12	4.5	40.6	45.1	
12	—	—	45.0	
12	—	—	44.9	45.0
15	4.9	39.6	44.5	
15	4.9	39.8	44.7	
15	—	—	44.7	
15	—	—	44.2	44.5
Ungerminated seed[2]				47.1[3]

[1] The seed coats were analysed with the stalks.
[2] 4 4 grams per 100 seeds.
[3] Average of 4 lots—maximum variation 0.4 mgs.

The P_2O_5 content of the wheat seedlings, given in Table 4, would indicate that maximum absorption was reached in 12 days in the cultures with the Fox sandy loam, while in the case of the other soils the P_2O_5 content of the seedlings was slightly greater on the 15th day than on the 12th day. The lower blank value for the 15-day period accounts for the apparent greater difference in the calculated P_2O_5 assimilation.

TABLE 4.—EFFECT OF LENGTH OF VEGETATION PERIOD ON THE P_2O_5 ABSORPTION FROM SOIL BY REWARD WHEAT AND A COMPARISON WITH THE NEUBAUER RYE SEEDLING VALUES

Soil	pH	Vegetation period in days	Mgs. P_2O_5				Neubauer value[2]
			Roots	Stalks[1]	Whole plant	Assimilation	
Fox sandy loam	5.7	12	—	—	49.7	4.7	
		12	—	—	49.7	4.7	
		15	—	—	49.6	5.1	
		15	—	—	49.8	5.3	4.1
Bondhead loam	7.0	12	5.3	39.9	45.2	0.2	
		12	5.4	39.9	45.3	0.3	
		12	—	—	45.4	0.4	
		15	4.9	41.3	46.2	1.7	
		15	5.1	40.9	46.0	1.5	
		15	—	—	46.0	1.5	1.6
Welland clay I	6.0	12	5.4	41.2	46.6	1.5	
		12	5.0	42.2	47.2	2.2	
		12	—	—	47.5	2.5	
		15	5.6	42.6	48.2	3.7	
		15	5.5	42.8	48.3	3.8	
		15	—	—	47.5	3.0	4.0
Welland clay II	4.6	12	5.7	39.8	45.5	0.5	
		12	5.5	40.1	45.6	0.6	
		12	—	—	45.4	0.4	
		15	5.4	40.8	46.2	1.7	
		15	5.5	40.3	45.8	1.3	
		15	—	—	45.8	1.3	4.6

[1] The seed coats were analysed with the stalks.
[2] Assimilation of P_2O_5 in mgs. by Cornell 45 rye grown for 17 days.

In the cultures on the Bondhead loam and Welland clay soils the data show that the P_2O_5 content of the roots varied within a narrow range. Although the P_2O_5 content of the whole plant did not vary to any great extent, the results on these three soils would indicate that the P_2O_5 absorption is reflected in the content of the stalks and not in the roots of the seedlings. These findings are in agreement with the observations of Ames and Gerdel (1), who concluded that by analysing only the leaves of the seedlings (wheat was used in their experiments instead of rye), essentially the same comparative results were obtained as by analysing both roots and leaves.

Comparing the absorption capacities of the wheat and the rye, it is to be noted that the wheat absorbed a slightly greater amount of P_2O_5 from the Fox sandy loam, and in the case of the Bondhead loam and Welland clay I, the 15th day absorptions by the wheat were approximately equal to the Neubauer values given by the rye. From the acid, unfertilized soil of the check plot II, however, the rye absorbed considerably more phosphorus than did the wheat. This is not unusual in view of the fact that rye, in comparison to other cereals, gives a relatively good yield on a poor soil (no rye has been grown on these plots), and it may be that a rye yield in response to fertilizer treatment may not correspond to the yields of other cereals under similar conditions. It is possible that the Neubauer values given by rye may be more indicative of the crop yields of the same species of plant than of the yields of other species having an entirely different genetic make-up.

If this were true, the choice of the extracting agent in the Neubauer seedling method may be a very important factor in predicting mineral nutrient deficiencies in soils with any degree of accuracy.

(*c*) *Efficiency of the Reward Wheat and the Cornell 45 Rye in the Absorption of Phosphorus from Different Soil Types.*

Considerable difference was evident in the results obtained with the Reward Wheat and the Cornell 45 rye on the Welland clay, and it was deemed of interest to make a further study of the phosphorus absorption capacities of these two grains from other soil types.

In Table 5 are given the P_2O_5 assimilations of the wheat (15-day vegetation) and the rye (regular procedure) from different soils. The data show that varying amounts of P_2O_5 were extracted by the two grains, but no correlation can be established between their relative absorption capacities.

Schumann (16) had observed that the wheat which he used absorbed less P_2O_5 than the rye in acid and neutral soils, while it took up almost as much P_2O_5 as did the rye from alkaline soils. No such relationship, however, can be derived from the assimilation values of the Reward wheat and Cornell 45 rye grown on soils which had a range of pH from 4.6 to 7.7.

The variations in the P_2O_5 absorption capacities of these two grains tend to support the views expressed in the discussion of the preceding experiments. The results would suggest the advisability of an extensive investigation on soils giving response to fertilizer treatment in order to determine which species of plant would give a more reliable index of the fertility of the soil.

TABLE 5.—EFFICIENCY OF P_2O_5 ABSORPTION BY REWARD WHEAT AND CORNELL RYE FROM DIFFERENT SOIL TYPES

Soil	pH	P_2O_5 absorption in mg. per 100 gm. of soil		Relative[3] efficiency of Reward wheat in %
		Cornell 45 rye[1]	Reward wheat[2]	
Welland clay II	4.6	4.3	1.4	32.5
Welland clay I	5.7	2.0	2.5	125.0
Brantford—Dunkirk silt loam	5.0	4.5	3.3	73.3
Newcastle—Durham loam	6.9	0.8	1.5	187.0
Tuscola silt loam	6.2	0.0	0.5	—
Tuscola loam 61	7.1	0.0	3.2	—
Tuscola loam 112	7.7	0.2	1.2	—
Bondhead loam	6.8	0.0	0.0	—
Bondhead loam 4	7.0	1.6	1.6	100
Dundonald—Bondhead sandy loam	7.0	2.2	3.4	154
Brookston loam 1″—4″	7.0	13.4	7.7	57.5
Brookston loam 4″—7″	7.3	15.0	8.6	57.4
Brookston loam 1″—6″	7.4	3.0	3.4	113
Dumfries—Bellefontaine loam	7.1	4.1	2.7	66.0
Fox sandy loam	5.7	4.1	5.2	127
Fox sandy loam 31	7.4	6.6	5.9	89.5
Fox fine sandy loam	7.5	1.0	2.8	280

[1] Regular procedure.
[2] Grown for 15 days.
[3] On the basis of the rye value taken as 100% absorption.

(d) Comparison of the Efficiency of Reward Wheat and Cornell Rye in the Absorption of Phosphorus added as $CaH_4(PO_4)_2$ to Sandy Loam Soil.

According to the work of Neubauer and Schneider (11) the range of P_2O_5 absorption by rye is from 0 to 25 mg. per 100 grams of soil. In studying the relative absorption capacities of the two grains, 25 mg. of P_2O_5 were added as $CaH_4(PO_4)_2.2H_2O$ per culture to two Fox sandy soils. The phosphate was mixed with the soil-sand mixture, saturated with distilled water and allowed to dry for 3 days. Sand was then added and the seeds planted in the usual manner.

The assimilations from the unfertilized soil and the recovery of the added phosphates by the two grains are given in Table 6.

In the wheat experiments no appreciable difference is evident between the 12th and 15th day recovery of the added phosphate, and only slight differences are indicated in the total assimilations by the wheat and the rye on the two soils. The apparent greater percentage recovery by the rye from the Fox fine sandy loam may be due to the lower assimilation of phosphorus from the untreated soil.

TABLE 6.—RECOVERY OF P_2O_5 ADDED AS $CaH_4(PO_4)_2.2H_2O$ TO TWO FOX SOILS, BY CORNELL 45 RYE AND REWARD WHEAT

Grain	Vegetation period in days	Treatment	Mgs. P_2O_5		Percentage Recovery
			Assimilation	Recovery	
Fox sandy loam pH 5.7					
Reward wheat	12	No treatment	4.7	—	—
	12	25 mg. P_2O_5	11.8	7.1	28.4
	15	No treatment	5.2	—	—
	15	25 mg. P_2O_5	13.3	8.1	32.4
Cornell 45 rye	17	No treatment	4.1	—	—
	17	25 mg. P_2O_5	11.4	7.3	29.2
Fox fine sandy loam pH 7.5					
Reward wheat	12	No treatment	3.2	—	—
	12	25 mg. P_2O_5	12.8	9.6	38.4
	15	No treatment	2.7	—	—
	15	25 mg. P_2O_5	12.6	9.9	39.6
Cornell 45 rye	17	No treatment	1.0	—	—
	17	25 mg. P_2O_5	13.6	12.6	50.4

(e) Efficiency of Reward Wheat and Cornell 45 Rye in the Recovery of Phosphates added to Silt Loam and Clay Soils.

The study of the relative assimilation capacities was extended to the recovery of phosphates added to a Brantford silt loam and a Welland clay soil, and involved the following treatments:

1. No treatment.
2. 50 mg. P_2O_5 as $CaH_4(PO_4)_2$.
3. 50 mg. P_2O_5 as 20% Superphosphate.
4. 50 mg. K_2O as KCl (added to the untreated soil).

Each fertilizer was thoroughly mixed with separate lots of 100 grams of soil and 50 grams of sand, transferred to the dish, covered with sand, and the grain planted in the usual manner.

The results of these experiments, given in Table 7, indicated that the rye recovered larger amounts of the phosphorus from the monocalcium phosphate treatment than from the 20% Superphosphate. Similar results are evident with the wheat on the Welland soil, but on the Brantford silt loam no significant difference can be noted in the recovery of the two forms of phosphate.

The addition of KCl did not appear to have any significant effect on the phosphate assimilation from the unfertilized soil.

These results also indicated that on the silt and clay soils the 15-day vegetation period for the wheat would be necessary for maximum recovery of large amounts of added phosphates.

In the 15-day period the wheat recovered only a slightly less amount of phosphorus of the monocalcium form and slightly more of the superphosphate than did the rye in the 17 days of vegetation.

TABLE 7.—RECOVERY OF P_2O_5 BY REWARD WHEAT AND CORNELL 45 RYE FROM SOILS HAVING A HIGH FIXATION CAPACITY

Treatment	Mg. P_2O_5 absorbed			Percentage recovery		
	Cornell[1] 45 rye	Reward wheat		Cornell 45 rye	Reward wheat	
		12 days	15 days		12 days	15 days
Welland clay pH 4.7						
No treatment	4.6	1.5	2.7			
$CaH_4(PO_4)_2$[2]	26.4	13.8	19.7	43.6	24.6	34.0
Superphosphate[2]	13.8	10.1	14.7	18.4	17.2	24.0
KCl[3]	4.0	0.6	3.6			
Brantford silt loam pH 5.0						
No treatment	3.4	1.3	3.3			
$CaH_4(PO_4)_2$[2]	28.4	16.0	25.5	50.0	29.4	44.4
Superphosphate[2]	19.5	15.0	25.3	32.2	27.4	44.0
KCl[3]	3.9	1.4	3.1			

[1] Data supplied by the Neubauer laboratory at the Ontario Agricultural College.
[2] Amount equivalent to 50 mg. P_2O_5.
[3] Amount equivalent to 50 mg. K_2O.

III. RELATIVE ABSORPTION CAPACITIES OF REWARD WHEAT AND THREE VARIETIES OF RYE—PETKUSER, ROSEN AND CORNELL 45

Various European workers (2, 5, 12) have shown that different varieties of rye absorb varying amounts of phosphorus from the soil. In Europe the Petkuser rye is used in the Neubauer seedling technique, while in the United States, Thornton found Rosen rye to be very satisfactory.

With regard to grain weight, Neubauer (11) recommends 4.0 g. per 100 kernels. Thun (20) in his experiments did not observe any effect of different grain weight as long as it was over 3.6 g. per 100 kernels, and only slight differences were obtained using seed weighing 3.68 and 4.85 g. per 100 seeds.

The grain weight recommended by Thornton and used in the laboratory at the Ontario Agricultural College is 3.5 g. per 100 kernels. To limit the factors to one variable, that of variety, the grain weight of the three varieties, Petkuser, Rosen and Cornell 45, were adjusted to 3.5 g. In the Reward wheat, however, the 4.4 g. weight was used as in the previous experiments.

The P_2O_5 assimilations by the different seedlings from several types of soil are given in Table 8.

Varying amounts of phosphorus were absorbed by the wheat in comparison with the Petkuser rye, while absorptions by Rosen and Cornell 45 rye were approximately equal, and in all cases greater than those by the Petkuser variety. The greater phosphorus extracting power of the two varieties used on this continent suggests the probability that the limit-values, 4.0 mg. P_2O_5, proposed by Thornton, applicable to Indiana soils, may be somewhat lower than the limit values, 6-8 mg. used by European workers, relative to the fertilizer requirements of the soils. In other words, the difference in fertilizer requirements between European soils and those studied on this continent may be greater than that indicated by the proposed limit values.

TABLE 8.—ASSIMILATIONS OF P_2O_5 FROM DIFFERENT SOIL TYPES BY REWARD WHEAT AND THREE VARIETIES OF RYE—PETKUSER, ROSEN AND CORNELL NO. 45

Soil	pH	P_2O_5 absorption in mg. per 100 gm. of soil			
		Petkuser rye	Rosen rye[1]	Cornell 45 rye	Reward wheat[2]
Brookston clay loam	5.6	0.4	1.4	—[3]	—
Welland clay	5.7	1.0	2.7	2.0	2.5
Burford loam, sp.	6.6	1.6	1.7	2.0	—
Brookston clay loam	6.6	1.4	1.9	2.0	—
Brookston clay	7.0	1.1	1.8	1.4	—
Sandy loam	7.0	0.4	1.4	1.2	—
Dumfries loam	7.0	2.6	5.5	4.1	2.7
Brookston loam 1″—4″	7.0	9.2	11.7	13.4	7.7
Brookston loam 4″—7″	7.2	12.0	13.6	15.0	8.6
Clyde clay	7.2	1.3	2.1	2.2	—
Fox sandy loam	7.4	3.6	5.6	6.6	5.9
Brookston loam	7.4	2.4	4.5	3.0	3.4

[1] Routine analysis 1937.
[2] Vegetation period 15 days.
[3] Insufficient sample.

SUMMARY AND CONCLUSIONS

Preliminary experiments with different species and varieties of plants included a study with Dawson's Golden Chaff wheat, Banner and Erban oats, O.A.C. 21 barley, Silver Hull buckwheat and Grand Rapids lettuce. The results are briefly discussed and some of the main inadequacies of these plants are pointed out.

The initial experiments with the Reward variety of spring wheat indicated possibilities of its adaptability in the Neubauer method, and an extensive study was made of its efficiency in the seedling technique of soil analysis.

A study of the blank values of the Cornell 45 rye and the Reward wheat indicated considerable variations in the phosphorus content of the ungerminated rye, as well as the sand culture seedlings, but no such variations were evident in the ungerminated wheat and its sand culture seedlings at any one stage of growth.

Considerable variations are evident in the phosphorus assimilations from various types of soil by these two grains, and investigations on soils giving crop responses to fertilizer treatments would be necessary in determining which cereal would give a more reliable index of the fertility level of the soil.

Studies of the recovery of phosphates added to sandy loam soils indicated that the absorption in 12 days by the wheat was approximately equal to the absorptions in 17 days by the rye. On silt loams and clay soils, however, the recovery of the added phosphates by the wheat reached a maximum in the 15 days of vegetation, at the end of which time it approximated the recovery by the rye using the regular procedure. These results gave a definite indication that maximum assimilations of phosphorus by Reward wheat were reached in the period from 12 to 15 days, as compared with the longer 17-day period advocated for the rye.

A study of the absorption efficiencies of the three varieties of rye would indicate that the Rosen rye used by Thornton and the Cornell 45 used in this laboratory gave approximately equal assimilations, which were in all cases greater than the phosphorus absorption by the Petkuser rye used by European workers.

The greater phosphorus absorption capacities of the Rosen and Cornell rye, in comparison with that of the Petkuser variety, would support the views that the fertilizer requirements, as governed by the respective cultural practices, were lower on the soils studied on this continent than on those studied in Europe.

The efficiency of the wheat in comparison with the Petkuser rye was greater on some soils and less on others.

And finally, it may be observed that the amount of so-called available phosphorus present in the soil depends not only on the soil condition and growth and development of the plant, but also on the phosphorus extracting power of the variety as well as the species of vegetation concerned, a factor that is probably governed entirely by the genetic make-up of the plant.

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SOIL SOLUTION STUDIES[1]

H. J. Atkinson[2]

Science Service, Dominion Department of Agriculture, Ottawa, Ont.

About forty-five years ago, the view was first put forward that plants obtain their nutrients from the solution present in the soil. This theory has survived and is now generally accepted, having been elaborated by such outstanding workers as Hoaglund, Burd and Martin of California. The soil solution is, therefore, the culture solution of the plant.

The methods commonly used for obtaining soil solution are displacement methods. A liquid is added to the surface of a column of soil and, as it percolates, it displaces the soil solution and forces it out at the bottom of the soil column where it can be collected. When the percolating liquid appears at the bottom of the soil column, all the soil solution has been displaced.

Schloesing, in 1866, was the first to study the soil solution and his method of obtaining it was to add water coloured with carmine to the surface of a soil column, in such a way as to simulate the action of rain. The course of the displacing liquid could be followed by watching the colour. Other methods of displacement that have been proposed, include one using oil under pressure on which Morgan at Michigan has done some work, and one using ethyl alcohol which Parker at Wisconsin has found useful. A method used extensively is that developed by Burd and Martin in California. The moist soil is packed into brass cylinders 17 inches long and 3 inches in diameter, about two kilograms of soil per cylinder. The bottom of the cylinder is a perforated plate covered with a filter paper. About 400 cc. of water are poured on the top of the soil and air pressure is applied and gradually increased until the solution runs out at the bottom. This is the method that has been adopted by the Division of Chemistry, Science Service Branch of the Department of Agriculture, Ottawa. Four brass cylinders are available, each being separately attached to the pressure line through a control valve, so that one, two, three or all four cylinders can be used as desired. Pressure is supplied by means of a tank of compressed air. A glass funnel is clamped against the perforated bottom of each cylinder and the soil solution is collected in 25-cc. graduated cylinders. By means of a small conductivity cell, successive increments of about 12 cc. of solution are tested. A continued gradual decrease in the conductivity value of successive portions of soil solution is an indication that the actual solution is becoming diluted by the displacing water.

The amount of pressure to be applied depends largely on the type of soil used. Soils of the heavier type will pack into the cylinders much more firmly than the lighter soils and consequently it will be necessary to apply more pressure to force out the solution. Pressures as high as 100 lbs. per sq. in. have been used.

[1] Presented before the Soils Group of the Canadian Society of Technical Agriculturists at Ottawa, Ontario, June 27-30, 1938.

[2] Graduate Assistant, Division of Chemistry.

An important factor to be considered is the moisture content of the soil. If this is too low, the displacing solution will percolate rapidly and dilute the solution almost from the first increment obtained. This difficulty is frequently encountered with soils direct from the field. In working with air-dried soils, it has been customary to remoisten these to between 50% and 60% of their water holding capacity as this gives optimum conditions for microbiological activity. This usually gives a sufficient moisture content for satisfactory displacement.

Much of the soil solution work in this laboratory has been done in connection with an investigation of the causes of brown root-rot of tobacco. This disease is quite prevalent in the tobacco growing district of Western Ontario, as well as in many parts of the United States and seems to follow certain crops, particularly corn, timothy and soybeans. A great deal of work has been carried out by many workers but so far the cause or causes have not been determined. Some of the evidence would indicate that the disease is due to the activity of some organism, but no causal organism has yet been isolated. Other evidence would indicate that it is not due to an organism but to some other cause. For instance, it has been shown that air-drying a soil for a period of two weeks or more will remove the disease from the soil, and no known pathogen is killed by such gentle treatment. Because of the fact that the disease disappears when a soil is air-dried, it is necessary to carry out investigations on the moist soil, and for this work soil solution studies seem to offer a method of attack. A sample of soil from a diseased area is taken, also one from an adjacent healthy area on the same soil type. Soil solutions from both are displaced and compared.

The effect of one crop on a succeeding crop may be due to: (a) excess removal of one or more nutrient elements by the first crop, thus causing a deficiency for the second crop; or (b) unfavourable soil conditions created by the decomposition of the residue (roots and stubble) of the first crop, which may affect the availability of some nutrient, or release substances which have an adverse effect on plant growth. To study this latter point, samples of the roots and stubble of a number of crops were collected, finely ground and mixed with air-dry soil. The soil was then remoistened and kept in loosely-covered glass containers in the laboratory for several weeks together with a sample of remoistened untreated soil. The soil solutions were then displaced and compared.

One of the difficulties encountered in this phase of the work was the large differences between the concentration of the solution from the untreated soil and of that from the soil treated with undecomposed plant residues. When a soil is kept at optimum moisture conditions in the laboratory, microbiological activity, including nitrification, takes place and there is an accumulation of nitrates. This results in a more concentrated soil solution since all the nitrates in the soil exist in solution and an increase in nitrates brings about an increase in the amount of soluble cations. When, however, undecomposed organic material of low nitrogen content, such as the plant residues used, is added to soil, there is no accumulation of nitrates (probably due to the activities of the cellulose decomposers) until the plant material becomes fairly well decomposed. Thus, when a soil was kept for three months after being remoistened, it was found that the

soil solution from untreated soil had a concentration of from three to five times that of the same soil which had been treated with various crop residues. Perhaps the addition of disintegrated filter paper to the untreated soil in an amount equivalent to that of plant residue used would have served to keep the concentrations of the soil solutions from treated and untreated soil more nearly of the same order. It may be of interest to note that, when alfalfa stubble was used, containing over 2% nitrogen (three to four times the amount of nitrogen in the other crop residues used) the concentration of the resulting soil solution was considerably higher than that from the untreated soil.

Soil solution studies have been used by Prof. Harris of the University of British Columbia in an investigation of the decline in growth and production of raspberry plants in certain districts of British Columbia. Similar work on this problem has been begun at our laboratories in Ottawa. Due to a limited knowledge of the composition of soil solutions, the method of attack is to select soil samples from diseased areas, and samples of the same soil type from adjacent healthy areas, and compare the composition of their soil solutions. This is the method followed in the study of brown root-rot of tobacco, as was indicated above, and seems to offer a satisfactory method of attack, particularly if samples of diseased and healthy plants are collected at the same time and from the same location as the soil samples, and these submitted to analysis.

In conclusion, it should be pointed out that no claim can be made that either of the problems mentioned previously has been solved by this method in our laboratory. Our work along this line has been in progress for only a little over a year, which is scarcely long enough to obtain definite results and have them checked under field growing conditions. Nevertheless, it is felt that important leads for future work have been established and that soil solution studies can form an important part of laboratory methods for the study of certain soil problems.

APPLICATIONS OF THE PHOTOELECTRIC COLORIMETER TO SOIL ANALYSIS[1]

C. L. Wrenshall[2]

Macdonald College, Quebec

The desire among soil workers for more rapid and less cumbersome methods of analysis is very evident. Colorimetric determinations or estimations of certain constituents have already taken a recognized place in soil analysis. Recently, attention has been given to the possibility of applying the spectrograph in problems of soil analysis. While the prospect of obtaining a complete or nearly complete specification of the soil constituents by a direct spectrographic examination is very enticing, many serious difficulties stand in the way and only time will tell what success may eventually be attained. Meanwhile the great advances in colorimetric technique, particularly through the application of the photoelectric cell, give promise of making the measurement of colour precise, thus opening the way to systems of analysis that will afford real savings in time and money. The present discussion proposes to examine the possibilities in this connection.

At the outset, it may be appropriate to review briefly the current position of colorimetry in relation to other analytical procedures. Colorimetric methods are commonly applied where comparative rather than absolute results are required, and where the concentrations of the substances to be determined are so low that gravimetric or volumetric determinations would be very cumbersome, or would involve errors of the same magnitude as colorimetry. Thus it might be said that the tendency in the past, continuing to the present, was to avoid colorimetry where possible because of the many sources of error inherent in it. There can be no question that gravimetric and volumetric methods have proven superior from the standpoint of reproducibility between individuals and between laboratories.

The assumption that the measurement of colour intensity is fundamentally as sound as the measurement of weight or volume appears to be generally justifiable; that is, the validity of the measurement depends upon the stoichometric relationships of chemical reactions. It is, then, pertinent to enquire what the causes of the lack of quantitativeness of colorimetric procedures are. It would appear that these are mainly associated with the inability of the human eye to measure color quantitatively.

The personal factor involved in making colorimetric readings visually is a matter of common experience. Eyes are not standard instruments and fail to give uniform and reproducible results. Variation between eyes may account for the lack of agreement between workers using a colorimetric method for a given analysis. The eye is subject to fatigue, and hence the same eye will give different results at different times.

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[2] Lecturer in Chemistry.

It is commonly observed that the use of a balancing type colorimeter leads to errors unless the concentrations of standard and unknown are very nearly the same. When this effect is noted it is usually stated that the reaction does not conform to Beer's law. This may be, and often is, an unjustified assertion. According to Beer's law, if the thickness of the solution is maintained constant the absorption of light at different concentrations of the same solute dissolved in the same solvent is an exponential function of the concentration. Mathematically, $I = I_0 e^{-klc}$, where I_0 is the incident intensity, I is the final intensity after passing through a length l of the medium, c is the concentration of absorbing material, and k is a constant characteristic of the absorbing material *and the wave-length of the light.* Beer's law, then, may be expected to apply only when monochromatic light is used. When the light is composed of different wave-lengths, as in white light, different constants are involved for the different wave-lengths and the total effect is quite complex. A substance appears coloured only because the different wave-lengths are absorbed to different extents.

One might ask what it is that the eye measures when comparing solutions in a colorimeter. It would be difficult to give a full answer to this question, but at least it is evident that the measure of light absorption given by the eye is a very indirect one which should not be made a criterion of the validity of Beer's law. For example, a solution appears blue because red and yellow light is being absorbed by the solute. The eye registers the depth or intensity of the blue colour, which appears to increase as the amounts of red and yellow light reaching the eye decrease.

Besides giving this very indirect measure of the intensity of transmitted light, the eye also registers differences in the tint or hue of the solutions under comparison. It is thus quite impossible for the above described indirect measure to operate successfully unless the solutions under comparison show exactly the same tint. If they do not they will never appear identical, and it is difficult to decide whether the greenish blue of the unknown is more or less blue than the blue of the standard. Extracts and solutions obtained from soil materials are so frequently tinted to some extent that this becomes a very common cause of failure in colorimetric methods. Frequently, also, a coloured reagent is used in the procedure, giving rise to the same type of complication.

Besides these faults, which are evidently associated with the method of measuring colour intensity, there are certain characteristics of colour reactions which sometimes make them difficult to apply. There is, for example, the question of colour stability. Many colours develop to a maximum intensity and then fade. When the colour intensity of the standard is also changing it is manifestly very hard to get quantitative information regarding this effect. There is also the question of interferences which inhibit or modify the colour-producing reaction. Difficulties of this class are by no means confined to colorimetric reactions, but are met with generally in analytical chemistry.

One might conclude, then, that the chief obstacle in the way of successful quantitative colorimetry is our inability to measure colour as accurately as we measure volume or weight. As a corollary to this con-

clusion it may be said that accurate measurement of colour intensity, or more strictly of light absorption (cf. Beer's law), will place colorimetry on a sound quantitative basis.

A number of photoelectric colorimeters have been devised and are described in the literature. These fall into two main classes: (a) the double photocell, null-point type, and (b) the single photocell, direct reading photometer type. Because of the unavoidable asymmetry in the response of two cells, and the probable differences between standard and unknown solutions, the first type suffers in some degree from the same disadvantage as visual colorimetry by balancing methods. The second type is theoretically to be preferred, because of simplicity of design and operation, and since it allows full use to be made of the advantages inherent in the use of colour filters. However, this type of instrument can only be successful when it employs a light source of absolutely constant intensity, a technical difficulty which has, until recently, prevented a full realization of the theoretical advantages.

Evelyn (4) has described a simple photoelectric colorimeter of the single photocell, direct reading type. The special advantages claimed for this instrument are as follows:

> Exceptional stability, secured by using a lamp of such low power requirement that it may be operated by a storage battery.
>
> Colour filters of very high selectivity are used, thus greatly extending the scope of the apparatus, and permitting accurate colorimetry in complex media (mixtures of coloured substances).
>
> Great simplicity and convenience of operation are afforded by the use of interchangeable glass test tubes in place of the conventional absorption cells.
>
> Complete mechanical rigidity, absence of moving parts, and a large safety factor in all important components eliminate the usual causes of unsatisfactory performance.

In his original contribution Evelyn gave a full description of the apparatus and general directions for its use. Since its introduction this instrument has found many important applications in the field of physiological chemistry, and its use is rapidly being adopted.

One of these colorimeters was placed in the laboratory at Macdonald College shortly after the publication of Evelyn's initial paper, and we are now in a position to verify his claims. It is a fact that, under practical conditions of operation, the instrument is capable of a high degree of precision and accuracy, and is so stabilized that calibration data remain applicable over long periods. By the use of selective light filters, the majority of colour reactions follow Beer's law. The useful range of reactions is usually extended below that of visual colorimetry, because of the selectivity of the filters and the sensitivity of the apparatus. Since the standard of comparison is 100% transmission by the blank, interference due to extraneous colours in sample solutions is eliminated.

A most admirable feature in connection with the colorimeter is its value as a research instrument for the full investigation of colorimetric reactions. The act of reading in no way affects the solution under test,

so that rapid serial readings are possible, and the stability of the colour, its development and fading, may be accurately charted in conjunction with the effects of reagent concentration and concentration of extraneous substances. The optimum conditions for carrying out analyses are thus readily established. The determination of iron in soil extracts by dipyridyl (1) and the ceruleomolybdate reaction for phosphate (2) has been reported on from this laboratory in papers which illustrate the use of the colorimeter in the investigation of colorimetric reactions. The success attained in making these colorimetric determinations quantitative has led us to visualize the possibility of working out a system of colorimetric analysis by which most of the common soil constituents could be determined.

It would appear that most of the soil constituents commonly determined enter directly or indirectly into colour reactions. Steenkamp (5) has reported on the use of micro methods of soil analysis, and in the system suggested, colorimetric estimations are offered for potassium, phosphorus, magnesium, aluminum, iron, and sodium. Of these, the colour-producing reactions are direct in the case of phosphorus, magnesium, aluminum and iron, while potassium and sodium are precipitated in combination with cobaltinitrite and zinc-uranyl-acetate, respectively, and the secondary components of the compounds separated enter into the colour reaction. The fact that Steenkamp, using visual technique, found satisfactory agreement between the results of micro methods and those of standard determinations lends strong support to the thesis that accurate determinations may be made by means of the photoelectric colorimeter.

Other constituents besides those mentioned above appear susceptible to colorimetric determination. Titanium is commonly estimated in this way, and manganese may be oxidized to permanganate producing a colour suitable for photometric determination. The determination of nitrates, nitrites and ammonia would doubtless be improved by the use of the photoelectric colorimeter, and the colorimetric micro-determination of total nitrogen would appear feasible (3). Colorimetric determinations have been proposed for a number of trace elements such as cobalt, copper, boron, and selenium.

Work on the application of the photoelectric colorimeter to problems of soil analysis is in progress in the chemical laboratories of Macdonald College.

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ERRATA

In Scientific Agriculture 18 : 3, November, 1937, in the article entitled "The Chemical Nature of Some Typical Soil Profiles of Saskatchewan", by J. Mitchell and F. F. Riecken, the following errata should be noted:

Page 112, Table 1, Profile No. 8, line A_1, $\frac{1}{2}'' - 1\frac{1}{2}''$, should read A_2, $1\frac{1}{2}'' - 9\frac{1}{2}''$.

Page 112, Table 2, Profile No. 8—Horizons and depths should read A_1, $\frac{1}{2}'' - 1\frac{1}{2}''$. A_2, $1\frac{1}{2}'' - 9\frac{1}{2}''$. B_1, $9\frac{1}{2}'' - 17''$.

Page 115, Table 5, Profile No. 8 should read A_1, 2.75, A_2, 8.5, B_1, 2.2.

In Scientific Agriculture 19 : 2, October, 1938, in the article "Note on the Use of Apples in Bread-baking," the following errata should be noted:

Page 83, Footnote 1—"Published as paper No. 139 of the Associate Committee on Grain Research, National Research Council and Dominion Department of Agriculture."

Page 684, Table 1—Control (no apple) loaf volume (cc.) should read 518.